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INFORMATION REQUIREMENTS ANALYSES FOR TRANSATMOSPHERIC VEHICLES

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FOR THE COMMANDER

Kenneth R. Boff

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13. ABSTRACT *(Maximum 200 words)*

An information requirements analysis was performed as the initial step in the design of crew system concept for future transatmospheric vehicles (TAVs). A knowledge acquisition, synthesis, and representation process was conducted. A baseline system description was prepared. Concept Maps were generated. A mission event sequence was developed. System architecture depictions were generated. Measures of effectiveness and performance were documented.

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PREFACE

This effort was conducted under exploratory development Program Element 62202F, Work Unit 7184 10 44, "Advanced Strategic Cockpit Engineering and Research," by the personnel of the Crew Station Integration Branch, Human Engineering Division, Crew Systems Directorate, of the Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio. Mr Gilbert G. Kuperman was the Work Unit Manager and provided technical direction to the team. The effort was supported by the personnel of Logicon Technical Services, Incorporated, Dayton, Ohio under Contract Number F33615-89-C-0532. Mr Robert Linhart was the Air Force Contract Monitor. Special acknowledgements are due to the following members of the Logicon technical staff: Dr Brian Zaff, who served as a consultant on the topic of concept mapping; Ms Karen Peio, who created the IDEF0 system function depictions; to Ms Iris Davis, who created the final versions of the IDEF0 and Concept Maps; and to Dr Annette Sobel, who was instrumental in developing the baseline TAV system description and measures of performance. Special thanks are due to LTC G. Mathews and Maj S. Clift of the National Aerospace Plane Joint Program Office, Wright-Patterson Air Force Base, Ohio, for their continuing support and encouragement during the conduct of the effort.

The unique knowledge and TAV system concept insights provided by the representatives of Headquarters, Strategic Air Command, Offutt Air Force Base, Nebraska, who served as subject matter experts during the knowledge acquisition and

representation phases of the effort, merits particularly strong recognition. Special acknowledgement must also be made 2LT S. Lind (AL/CFHI), who assisted the author during one of the technical interchange meetings held at SAC Headquarters.

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GLOSSARY

AAA	Anti-aircraft artillery
AD	Air defense
AF	Air Force
AL	Armstrong Laboratory
AOA	Angle of attack
BDA	Bomb damage assessment
BIT	Built-in-test
BTU	British thermal unit
CCCD	Crew centered cockpit design
C^3I	Command, control, communications, and intelligence
CG	Center of gravity
CNI	Communications, navigation and identification
CVI	Crew/vehicle interface
DOB	Defensive order of battle
DoD	Department of Defense
DSCS	Defense satellite communication system
E	Mental effort (SWAT)
ECS	Environmental control system
EOB	Emitter order of battle
ESM	Electronic support measures
ETA	Expected time of arrival
EVA	Extra-vehicular activity
EW	Electronic warfare; early warning
F	Farenheit
FCS	Flight control system

GCI	Ground controlled intercept
GPS	Global positioning system
HSD	Horizontal situation display
IDEF	Integrated computer-aided manufacturing definition
IFF	Identification: friend or foe
INS	Inertial navigation system
IRA	Information requirements analysis
LOC	Lines of communication
MES	Mission event sequence
MDL	Mission data load
MILSTAR	Miltary strategic, tactical and relay satellite
min	Minute
MOB	Main operating base
MOE	Measure of effectiveness
MOP	Measure of performance
MPD	Multipurpose display
MRD	Mission rehearsal device
MSTO	Multi-stage-to-orbit
Mux	Multiplex
PCS	Performance criterion specification
P/L	Payload
q	Dynamic pressure
ROE	Rules of engagement
RTB	Return to base
S	Psychological stress (SWAT)
SAC	Strategic Air Command

SAM	Surface-to-air missile
SAR	Synthetic aperture radar
SEAD	Supression of enemy air defenses
sec	Second
SSTO	Single-stage-to-orbit
ST	Self test
SWAT	Subjective workload assessment technique
T	Time stress (SWAT)
TA	Time available
TAC	Tactical Air Command
TAV	Transatmospheric vehicle
TDRSS	Tracking and data relay satellite system
TIM	Technical interchange meeting
TR	Time required
TTG	Time-to-go
VMC	Visual meteorological conditions
VSD	Vertical situation display
WCA	Warnings, cautions, and advisories
WST	Weapon system trainer

SECTION I

INTRODUCTION

PURPOSE

Hypersonic, transatmospheric vehicles (TAVs) may provide a future capability to achieve the national military goals of "Global Reach/Global Power." TAVs will be capable of single-stage-to-orbit low earth orbit payload deployments and operations, as well as performing hypersonic cruise in the Mach 6+ regime. Several international programs (e. g., Japan, Germany, Russia, France, United Kingdom, United States) are currently being pursued to develop, mature, and demonstrate the required aeropropulsion, materials, flight control, and structures technologies from which to develop a variety of TAV systems. These system concepts include single-stage-to-orbit (SSTO), multi-stage-to-orbit (MSTO), atmospheric cruisers, and space-capable aircraft.

Technologies currently being developed for demonstration under the United States' National Aerospace Plane (NASP, the X-30 experimental hypersonic flight test vehicle) program will be applied to create a fleet of operational vehicles. Mission capabilities will be achieved through the combination of organic (on-board) and containerized payload subsystems.

Positing the future application of X-30 technologies to military aerospace systems, the question of how to design a crew system for hypersonic flight can begin to be addressed. A number

of significant crew-related issues must be investigated and resolved in developing TAV system concepts. Crew size and specialty must be identified. A crew size of between two and four crewmembers appears most realistic. Crewmembers might be pilots, payload specialists, or cross-trained in both roles. The design of the individual crew stations will have to reflect this degree of specialization and will have to support appropriate levels of task sharing, allocation of crew tasks to the primary/secondary crew positions, provide manual override capabilities in cases where the primary execution of a task is automated, and resolve any ambiguities regarding which crewmember has control over which TAV subsystems. The cockpit environment will have great impact on the complexity of the required life support system. The cockpit may be fully pressurized to (near) sea-level conditions or it may be at reduced atmospheric pressure (3.5 to 14.0 psi). The crew's work environment may, then, range from "shirtsleeve" through full pressure suit. The atmosphere may be pure oxygen or a dual gas mixture. Mission requirements for performing extra-vehicular activities (EVAs), either within the TAV payload bay or in conjunction with another space asset, will also impact the crew compartment design. The crew compartment-to-payload bay interface may be an airlock. Alternatively, it may be a direct access hatch. In the latter case, provision must be made for depressurizing/repressurizing the crew compartment. Provision must be made for the crew to store, checkout, and don/remove any required EVA suit. The crew

system interface must be designed for operation over the expected range of cockpit atmospheric pressure and temperature conditions. It must also be operable by crewmembers garbed in full pressure suits (if required). The crew escape concept adopted will impact the overall crew compartment design. If, for example, the cockpit is also an escape pod, size and volume constraints may be significant. This will also impact the design of crew ingress/egress to/from the cockpit. Requirements for external vision will also have significant impact on crew station design. If direct visual contact with the outside world is mandated, the size and location of the windows will interact with the visual contact requirement and with the positioning of crew system controls and displays. If indirect (i. e., sensor-mediated) contact is adopted, display size, luminance, resolution, and other visual interface design issues will have to be resolved.

The Crew Station Integration Branch, Human Engineering Division, Crew Systems Directorate of the Air Force's Armstrong Laboratory (AL) has initiated an exploratory development activity directed, in part, to investigating the crew system design and life support system requirements associated with TAVs. The paper presents the approach, methodology, and some of the preliminary findings of this investigation.

OVERVIEW OF METHODOLOGY

An Information Requirements Analysis (IRA; Kuperman and Sobel, 1992) was performed in order to lay the foundation for the

TAV crew station design process. The IRA was composed of four interrelated steps: the creation of a baseline TAV system description, the generation of a Mission Event Sequence (MES), the development of system architecture flow diagrams, and the identification of candidate measures of performance (MOPs). The IRA process is shown as a flow diagram in Figure 1.

Baseline TAV System Description: Since no TAV system currently exists, no system documentation (e. g., avionics manuals) existed. It was necessary to form a conceptual TAV system description based on the synthesis of domain expertise resident in the NASP/X-30 program. The proceedings of the first three International Aerospace Plane Conferences, held annually under the sponsorship of the American Institute of Aeronautics and Astronautics, together with press releases on the program issued by the Public Information Office of the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, formed the body of the source material. Additional information was garnered from the technical sessions on Aerospace Planes and Hypersonic Vehicles presented at the 1992 Society of Automotive Engineers Aerospace Atlantic Conference and Exposition held in Dayton, Ohio during 7 through 10 April 1992. (Unfortunately, most of the presentations at the Aerospace Atlantic Conference were "oral only" and not included in a conference proceedings or paper reprint.) During the information gathering and synthesis portions of the IRA effort, attention was directed to the identification of system capabilities which could be projected

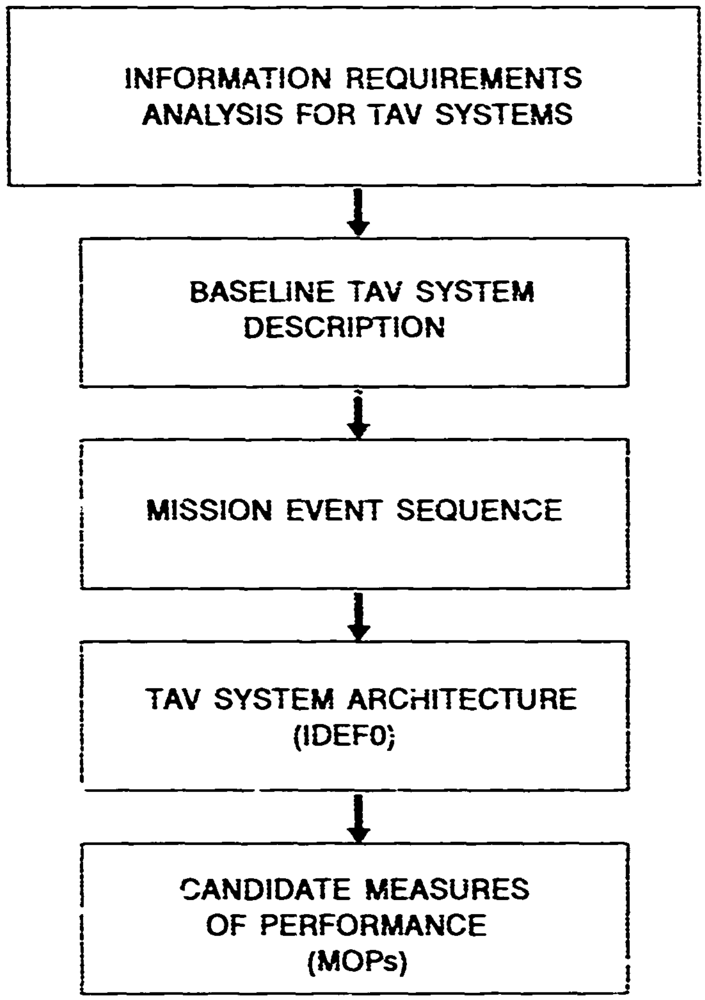

Figure 1. Information Requirements Analysis Flow

into future TAV system concepts. This literature was reviewed and a synthesis of the diverse elements was created. The knowledge acquired during the literature review was captured and represented in the form of a Concept Map.

Concept mapping (McFarren, 1987) is a knowledge elicitation and representation technique currently enjoying application in the Artificial Intelligence systems development community.

Concept maps (also known as semantic networks) originated with Quillan's Semantic Networks (1969). They represent knowledge as a linked structure of objects or events illustrated as nodes. These nodes are connected by links or arcs that represent relationships between objects and facts (Eberts and Brock, 1987). Thus, semantic maps graphically depict a knowledge domain where concepts (key ideas) are represented as nodes, and the links between the nodes represent relationships between the concepts. Since the objects of the map are exhibited as being subordinate or superordinate to related objects, a semantic network may be seen as a hierarchical representation of the illustrated domain. A semantic network of TAV crew systems was prepared as part of the process of the function requirements definition process.

This technique has been demonstrated to effectively develop concepts and understanding of system functionality. For example, McFarren (1987) utilized the semantic network approach in concept mapping as an interactive technique to aid communication between designers and system users, to identify key concepts involved in

problem solving, and to represent models of problem areas. A natural extension of this concept mapping methodology was used by McNeese, Zaff, Peio, Snyder, Duncan, and McFarren (1990) to elicit expert knowledge from pilots. Pilots were interviewed and maps were developed representing individual pilot's views of a target acquisition task. It was found that while configurations of pilot concept maps differed, key concepts and links represented a mental model of the target acquisition task that could be used for further information analyses.

The semantic maps developed for TAV IRA are primarily a synthesis of concepts derived from the existing international aerospace plane program documentation. The concepts appearing in this literature were clarified and expanded upon through discussion with operational personnel and on the basis of the current systems engineering approach to modern military aircraft functional design.

Under the conventions of concept mapping, an object-oriented decomposition is performed and a Parent-Child relationship is created. Objects are linked by relational descriptors, i. e., "facts" regarding the nature of the inter-object relationship. Figure 2 (adapted from McNeese, et al., 1990) provides an illustration of the syntax employed in creating a Concept Map. Examples of CONCEPT-RELATIONSHIP-CONCEPT triplets appropriate to the TAV system concept are: TAV-has-Subsystems, Subsystems-include-Crew/Vehicle Interface (C/VI), C/VI-has-Flight Controls, Flight Controls-are-Stick, Stick-has-Cursor Controller, etc.

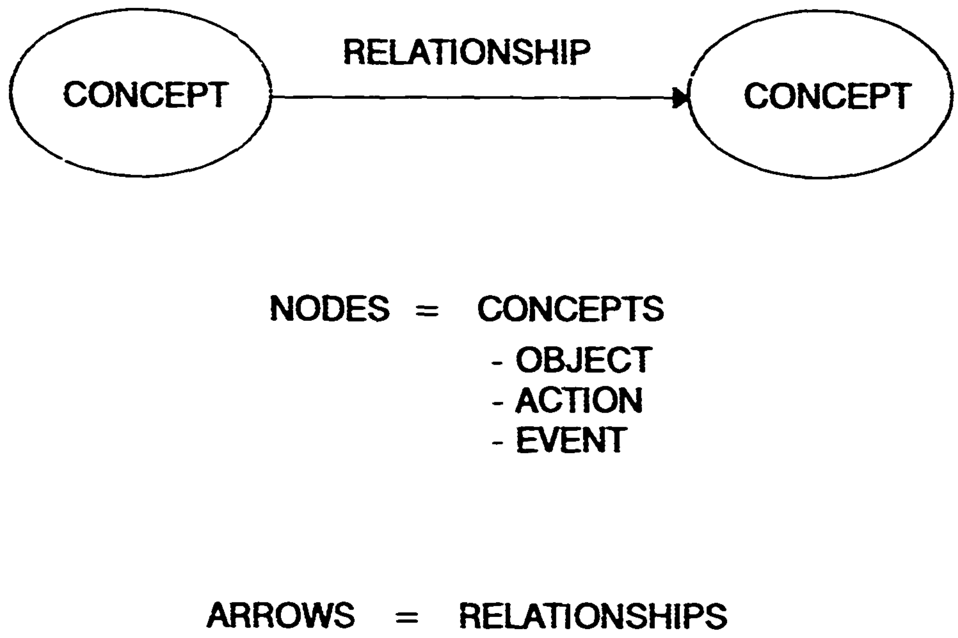

Figure 2. Concept Mapping Syntax (After McNeese, et al., 1990)

Objects are depicted as "bubbles" with links as their connections. Figure 3 depicts an extract from a notional TAV Baseline System Concept Map. Once the graphic identification of system objects and relationships was completed and verified, a systems analyst created a textual description of the TAV Baseline System similar to the introductory material found in an aircraft flight manual. (A recent example of the application of the Concept Mapping technique to the conceptual decomposition of a future military capability may be found in Peio, Crawford, and Kuperman [1991]).

MES: A notional TAV mission description was created in the form of a function/flow diagram. First, the mission phases were identifed. The phases fell into two general groups: those system functions performed between the receipt of the Air Tasking Order and the Pre-Flighting of the TAV, and then Takeoff through Post-Flight activity. Each phase was further decomposed into a logical sequence of TAV System Functions. Approximately thirty distinct System Functions were identified. They included: Perform Trans-Orbital Maneuver, Configure the C/VI, Communicate: Transmit, etc. Again, once the function/flow diagrams were verified, a textual description was prepared to accompany the graphics. Figure 4 presents the TAV mission phases in the form of a flow diagram.

System Architecture: System architecture depictions ("wiring diagrams") were prepared for each System Function identified in the MES. The tool used was the Integrated Computer-Aided

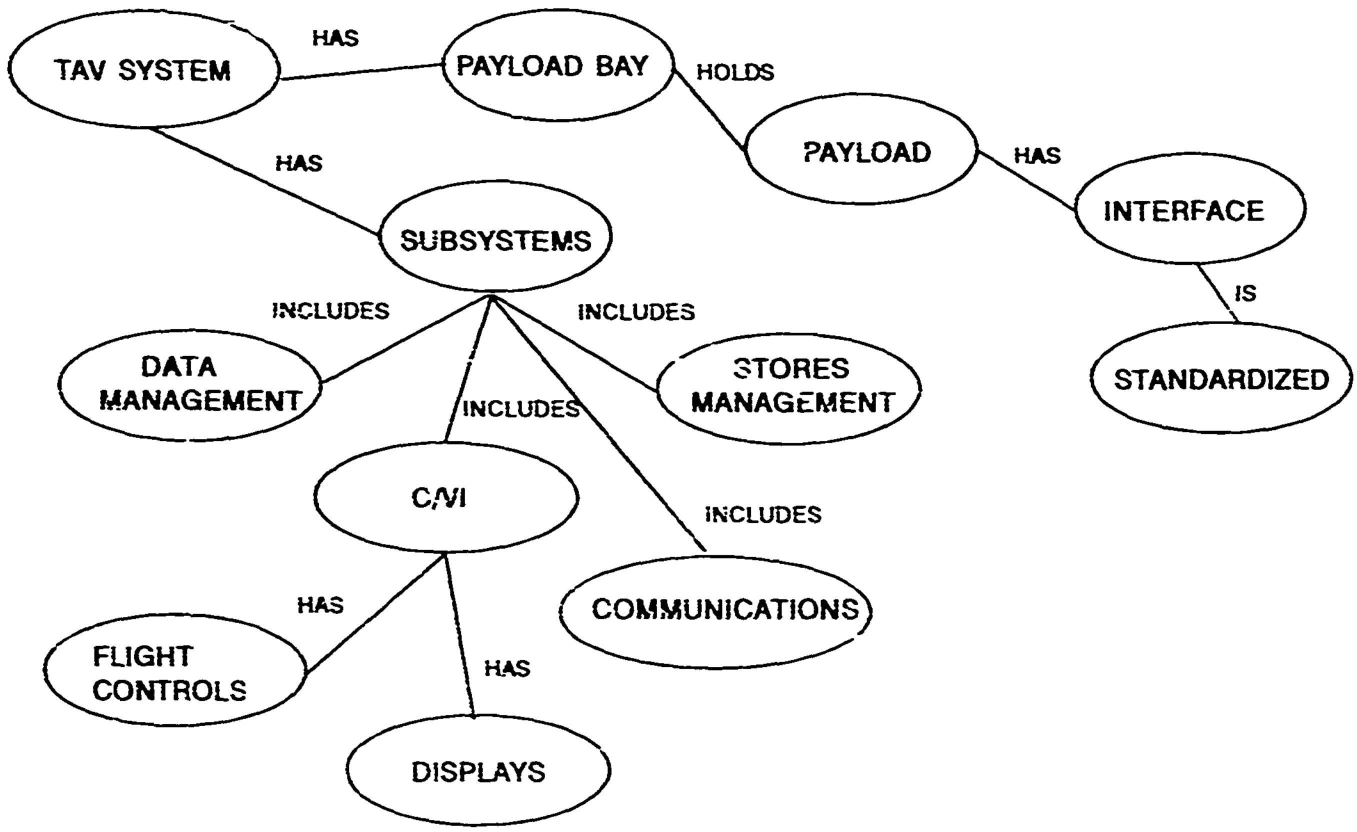

Figure 3. Notional Concept Map for Transatmospheric Vehicle

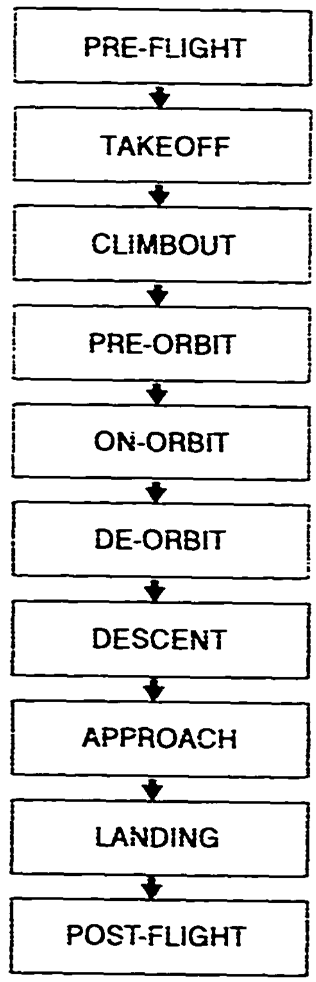

Figure 4. Transatmospheric Vehicle Mission Event Sequence: Mission Phases

Manufacturing Definition (IDEF) graphical reporting method.

The IDEF0 (IDEF, level 0) technique is a system description tool. It is an "activity" model version of the Structured Analysis and Design Technique (SADT) developed by SofTech in the early 1970s (Marca and McGowan, 1988), and is primarily used in military and aerospace applications. The IDEF0 decomposes the functional and informational components of a system from the top down. IDEF0 methodology has recently been used to analyze bomber flight management systems (Peio, Crawford, Kuperman, 1991) as well as the Crew-Centered Cockpit Design (CCCD) methodology being created under an Air Force advanced development program (Anderson, Ever, Green, and Wallace, 1990). CCCD is creating a family of computer-aided design tools to support a structured and largely automated cockpit design process.

The IDEF0 model is a coordinated set of diagrams which provide a structured representation of system and subsystem activities, relationships, and data flow. The boundaries of the model are defined by a top-level box (parent diagram) that is decomposed into sub-layers (child diagram). The decomposition process continues until all activities are identified in hierarchical fashion to a predetermined level of detail. Each IDEF0 diagram defines a specific topic and each subsystem activity is defined with its information input, output, constraining factors, and mechanisms. Thus, the hierarchical relationships are illustrated by the parent/child diagrams. The parent functions are decomposed into three to six child functions

or tasks until, as stated above, questions about the system are explained in enough detail to accomplish the purpose of the model.

The IDEF0 model includes two descriptors: boxes that represent activities (tasks that are performed by the system) and arrows that depict the "operators" of the system. These operators may be information, rules, or outcomes of other activities. The arrows also function as connectors between activities, (and) illustrate interdependencies, represent feedback loops (between activities), and provide information flow throughout the system.

Arrows enter a box from three directions. Input arrows enter a box from the left and represent operations the box (activity) will use or transform while executing the task under consideration. Control arrows enter the box from the top and represent constraints that govern the activity. Mechanism arrows enter the box from the bottom and represent how (or by whom) the activity is getting/being done. Output arrows exit the box on the right and define the product of the activity. Figure 5 shows an example of an IDEF0 box (adapted from Marca and McGowan, 1988).

Control arrow functions include constraints that may be rules, such as Defense Guidance or Standard Operating Procedure (SOP), or data that define the boundaries under which each activity occurs. According to the IDEF0 protocol (Marca and McGowan, 1988), all activity boxes in an IDEF0 diagram must have

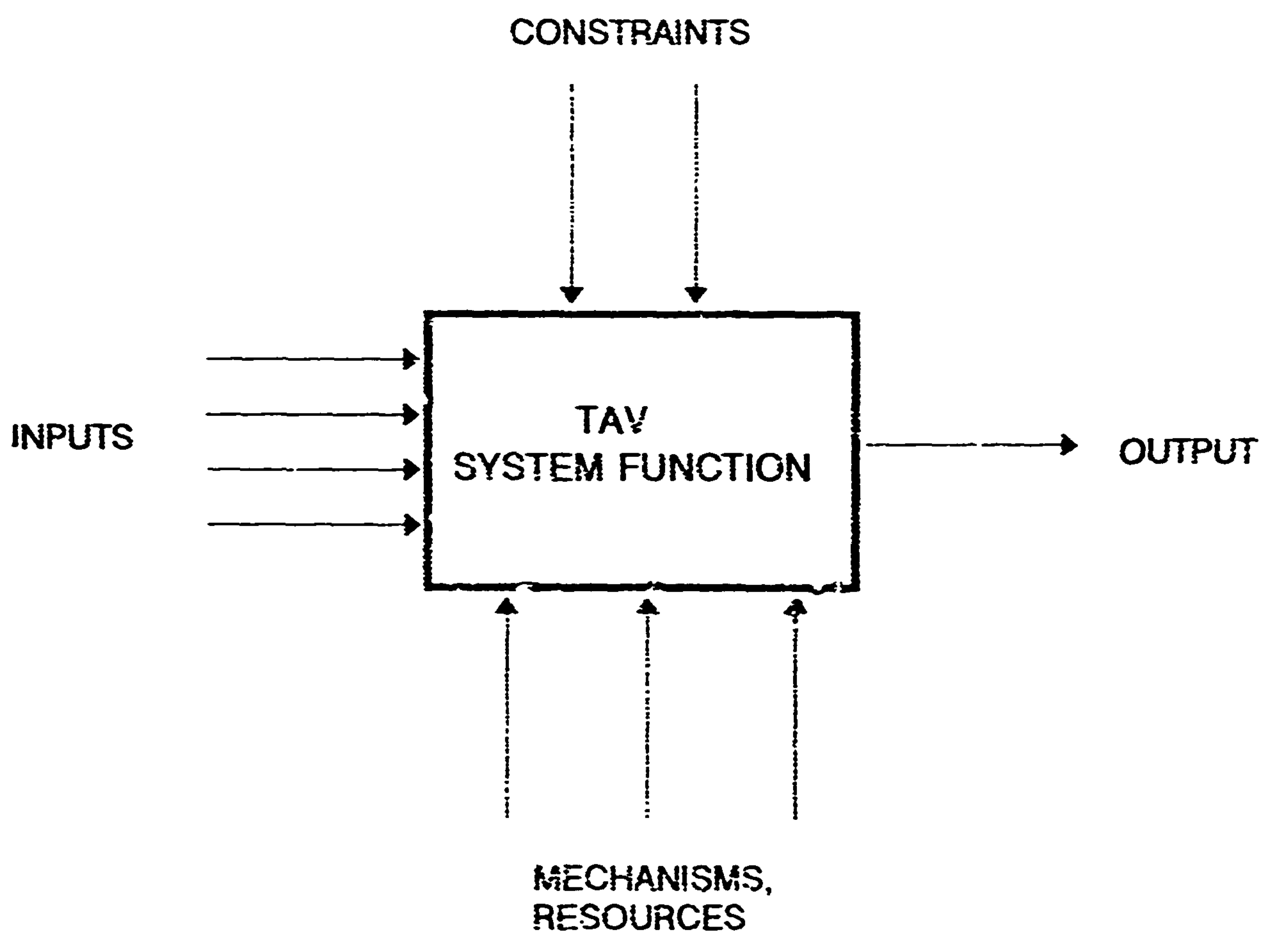

Figure 5. IDEF Graphical Convention

at least one control arrow. However, input arrows are not required for all boxes. When an arrow can operate as input or control, then by default the arrow is used as a control. In TAV system concept, mechanism functions are usually accomplished by the crew or inputs from other subsystems. Output arrows typically serve as a source of input, control, or even a mechanism for subsequent activities or feedback loops to previous activities, and thereby illustrate the interdependencies of activities within the system. Arrows may contain several components which may branch or join other arrows as input, output, or mechanisms for activity boxes.

An IDEF chart consists of a sequence of processes. Inputs to a process appear from the left and outputs flow to the right. Constraints are imposed from above. In the case of the TAV system concept, the contraints included Tactical Doctrine, Rules of Engagement (ROEs), and Standard Operating Procedures. Resources and mechanisms required for the execution of the process are shown as coming from below. In the case of this IRA, they served to identify the specific TAV subsystem(s) employed by the automation or the aircrew in process execution. A recent example of the application of the IDEF methodology to depicting the interrelationships between the components of a large, complex future avionics capability is to be found in McNeese, et al., 1990.

Candidate MOPs: Measures of effectiveness (MOEs) are differentiated from MOPs. MOEs are regarded as system-level

descriptors of desired capabilities. For example, MOEs might include statements regarding system survivability, maintainability, and flexibility. Somewhat more TAV-specific MOEs might include assured access to space, airplane-like operations, global operating range, and capability to perform hypersonic cruise. MOPs, in contrast, are generally defined at the subsystem-level and are more amenable to direct exploration, particulary early in the system concept definition/exploration stages of the system acquisition process. A methodology for performing the decomposition of system measures is developed in Erickson, 1986.

Each of the TAV System Functions, identified in the MES and depicted in the IDEF0 charts, served as a candidate MOP. The process of documenting the MOPs was essentially that of creating a crew procedure or checklist for the accomplishment/monitoring of the TAV System Function. The tool employed for MOP creation was the Performance Criterion Specification (PCS; [Lehman and Jenkins, 1990]). The PCS is a formatted, five-part worksheet (as shown in Figure 6.).

First, the mission or mission phase is specifically identified. The mission phases identified in the MES were: Pre-Flight, Takeoff, Climbout, Pre-Orbit, On-Orbit Operations, Descent, Approach, Landing, and Post-Flight.

Next, a specific System Function (from the IDEF0 architectural representations) is identified. TAV System Functions include: Configuration of the TAV (preparatory to a

MISSION/PHASE:
SYSTEM FUNCTION:
CREW TASK(S):
CONDITIONS:
SPECIFICATION FOR SUCCESSFUL COMPLETION OF TASK:

Figure 6. Performance Criterion Specification Worksheet

flight maneuver), Configuration of the C/VI, Tailoring of the multipurpose display formats, Monitoring engines, Servicing the payload(s), Monitoring subsystems, etc.

The third portion of the PCS deals with Crew Task(s) to be performed. This is recorded in the form of a crew procedure or checklist to be accomplished in carrying out the System Function.

The fourth section of the PCS deals with the Conditions under which the System Function is being carried out. It is a detailed description of the external and system states expected to obtain and may include a statement of the pertinent ROEs.

Lastly, the PCS contains a Specification for Successful Performance of the Task. This portion of the PCS is the essence of the MOP and it includes quantitative metrics defining the requirements for successful accomplishment of the previously enumerated Crew Task(s). The metrics are defined in terms of speed (time), accuracy (and/or errors), and expected workload.

SUBJECT MATTER EXPERTISE

In that no true subject matter expertise exists, because no TAV system exists or is even currently under design, the normal process of interviewing domain experts to elicit, capture, and represent their specialized knowledge could not be attempted. As was already mentioned, knowledge regarding possible TAV system concepts was derived from publications and presentations having to do with the X-30 technology demonstration program. During the course of this research, the authors participated in several

technical interchange meetings (TIMs) with members of the NASP Joint Program Office. Of particular importance were the meetings of 16 August 1991, at which the AL team presented their overall approach to performing the TAV IRA, and 11 December 1991, at which AL provided an interim review of the work then in progress. The 11 December meeting was also attended by representatives of the Strategic Air Command of the Space Command.

Additional TIMs were held at Headquarters, Strategic Air Command, Offutt Air Force Base, Nebraska. The first TIM (28 August 1991) presented the AL team's assumptions and methodologies. The second SAC TIM (24 February 1992) served to obtain operational comment regarding the TAV system concepts (i. e., the concept map), the notional TAV mission (i. e., the MES), and the initial attempts at the crew procedures (i. e., the IDEF0 depictions and the MOPs). A very useful suggestion elicited at the second SAC TIM was that the SR-71, a supersonic (Mach 3+), high-altitude reconnaissance platform which employs specialized avionics and flight capabilities, and which also has a two-man crew, should be exploited as an analogous system. As a result of this suggestion, discussions of the IRA project were held with personnel highly experienced in both the piloting and systems operations crew positions of the "Blackbird."

SUMMARY OF THE REPORT

Section II presents the description of the TAV system concept. It begins with a discussion of possible missions for a

hypersonic flight vehicle. Next, a detailed description of the vehicle and its major capabilities is presented. This is followed by the identification and description of the TAV's avionics capabilities. Here, emphasis is on the interface between the crew and vehicle and avionics. The detailed TAV Concepts Maps are presented at the end of the Section. The Concepts Maps are divided into a TAV System Overview, TAV Missions, Measures of Effectiveness, Payload Concepts, TAV Subsystems Overview, Crew and Controls/Displays, Communications/Navigation/Identification Subsystem, Electronic Support Measures, Flight Control, "Self-Help," Environmental Control, Stores Management and Thermal Management, Propulsion, and Data Management.

Section III presents the Mission Event Sequence. Pre-mission activities (e. g., mission planning, vehicle preparation) are identified. Each of these activities is described in both text and flowchart formats. The mission is divided into nine phases (Takeoff through Post-Flight). Each mission phase is decomposed to identify major TAV System Functions.

Section IV is a description of the TAV System Architecture. IDEF0 charts and accompanying text are employed to describe how the crew uses the TAV subsystems to accomplish each of the System Functions.

Section V contains the Measures of Effectiveness and Performance. A Performance Criterion Specification is present for each TAV System Function.

SECTION II

BASELINE TRANSATMOSPHERIC VEHICLE (TAV) DESCRIPTION

GENERAL

This section provides a top-level description of a notional, operational TAV system for the purposes of defining notional mission event sequences and timelines. These descriptions, in turn, support the IRA which make up the main body of the report. The Baseline System Description is motivated by a brief discussion of the missions with which an Operational TAV fleet might be tasked. Each mission type is then described in somewhat greater detail. A detailed discussion of a generic TAV system is then presented. It is followed by descriptions of the general capabilities of each of the TAV's major subsystems.

MISSION NEEDS

United States policy on space requires assured access to space. It is based on awareness of the world military situation including indications and warnings, surveillance, and capabilities for performing technical intelligence. Coupled with the capability to perform power projection on a global basis, access to and control of the "high frontier" is a critical component of national policy.

The Department of Defense (DoD) is charged by direction with assuring that United States establishes and maintains an assured space mission capability, even under adverse circumstances. The

Air Force, as the lead DoD space agency, has direct responsibility for carrying out this policy. The TAV platform serves as a critical component of the Air Force response to its mission direction.

A manned space presence provides the flexibility required to conduct complex missions. The system, including the crew, can perform cargo delivery and assembly, space station proximity operations and rescue, space asset (satellite) servicing and repair, satellite configuration changes, and retrieval. The direct operation of mission-specific (not deployed) payload (P/Ls) also benefits from crew capabilities.

MISSION TYPES

Potential TAV operations range from routine through sustained surge. Routine operations are preplanned and prescheduled. Short-notice tasking would be based on sufficient lead time to fully preplan the mission, prepare and onload mission P/L, and preflight the TAV ready for fueling. Response to No-notice tasking would begin with an empty (no P/L, no fuel) TAV or may require P/L changeout. "Burst" operations, which might be required during a crisis situation, would necessitate multiple TAVs to be prepared and takeoff in as short a time as possible. Sustained surge operations, as might be required under conditions of severely heighten world tension or during wartime, would involve the entire TAV fleet. An additional ground crew shift would sustain round-the-clock TAV preparation. Abbreviated

inspection procedures and accelerated maintenance operations would increase aircraft availability.

The TAV is capable, based on mission P/L and organic capabilities, of accomplishing a variety of military missions. Mission types include:

Space Transportation: As an air-breathing space launch vehicle, the TAV can perform the direct insertion of P/Ls, including personnel, into TAV-compatible orbits, the indirect insertion of powered P/Ls into higher orbits, and the delivery of materials to space activities. High TAV availability will assure access to space on demand. Selected mission P/Ls include support of space-based communication, surveillance, and navigation systems. As a flexible space transportation system, the TAV will perform satellite insertion, satellite recovery, exchange of personnel with manned orbital assets, component delivery for space asset assembly, conduct space-based experiments and tests, and support the resupply and repair of space assets. High TAV availability also makes it very suitable for the possibility of rescue of personnel and the emergency recovery of equipment/space assets.

P/Ls may be deployed directly into low Earth orbit. For P/L deployments into higher or geostationary orbits, a P/L booster may be required. Rendezvous and retrieval missions would include the capture of and return of equipment, data, and/or experimental products. Space asset maintenance, repair, and servicing would be performed during rendezvous and revisit mission types. The return of space assets to the ground for major overhaul and/or

repair/refurbishment would be performed during rendezvous and return missions.

Space Operations: In addition to satisfying the support needs of space-based systems, the TAV will be capable of protecting them from hostile forces.

Surveillance: Performing long range/high speed orbital/ suborbital area, lines of communication (LOC)/route, and point surveillance by exploiting the capabilities of mission-specific sensor P/Ls. The TAV adjusts flight profile in keeping with sensor operation portion of mission plan. Sensor management may be automated (TAV or P/L includes sensor management subsystem) or under the control of the TAV crew (mission plan).

Force Projection: The TAV provides a means for reinforcing the global presence of the United States military. Sorties can reach any point on the Earth in as little as one hour from bases within the United States. The TAV is capable of providing a day/night, all-weather immediate response to a crisis situation anywhere in the world. Tactical flexibility is achieved on the basis of platform endurance and inherent survivability, orbital or atmospheric loiter, maneuverability, and missionized P/Ls. The P/L can include weapons (and target acquisition sensors, if required) to perform surgical attacks against selected targets. The target set may include critical C^3I nodes, military facilities, communications facilities, storage facilities, transportation networks, and defensive installations. The TAV may adjust flight profile to achieve weapon separation parameters.

Offensive Operations: The TAV system is capable of responding to a variety of tasking for offensive operations. These mission types include:

Low-Intensity Conflict: (Similar to Force Projection)

Theater Missile Defense: The TAV performs an offensive counter force mission by searching large areas for critical mobile targets. Targets are detected by P/L sensors and struck on confirmation by the TAV crew (imaging sensor display).

Suppression of Enemy Air Defense (SEAD): Selected, fixed enemy air defense sites (including indirect threats [EW/GCI], direct threats [AAA, SAM]), and AD command centers are acquired and struck by the TAV. The AD elements are not (necessarily) threats to the TAV. The purpose of the SEAD mission is to enhance the survivability of other friendly forces (bombers, reconnaissance, fighters).

Counter-Terrorism: Similar to Force Projection but with the inclusion of training and staging area targets.

BASELINE TAV SYSTEM

The TAV is capable of performing the variety of military missions identified above. In shape, the aerospace vehicle will probably be a lifting body with a chisel-like nose, small horizontal delta wings, a horizontal tail incorporating stabilator flight control surfaces, and dual vertical fins. The TAV will be a relatively large aircraft with a takeoff gross weight in the 400 to 600 thousand pound range. It will have a

mission range of between 10 to 12,000 nautical miles. The TAV will probably have three multi-mode engines to provide aeropropulsion.

Propulsion is provided by multiple airframe-integrated, environmentally safe, liquid (slush) hydrogen-fueled, air-breathing (ambient air is the propellant oxidizer, greatly reducing propellant consumption and TAV takeoff weight) ramjet/scramjet engines, along with small rocket motors. The TAV is capable of reaching hypersonic speeds of up to Mach 25 (approximately 27,000 feet/sec or 17,000 mph; orbital velocity) through the atmosphere and achieving low Earth orbit. For takeoff and speeds below Mach 6 and altitudes up to about 75,000 feet, the subsonic (velocity of air flow in the engine combustor) ram-air fed jet (ramjet) engine is employed. (A low speed system mode of the engine will probably be employed up to about Mach 3.) For higher Mach numbers (above Mach 6) and altitudes (to about 175,000 feet), the supersonic combustion ramjet (or scramjet) engine cycle is utilized. The scramjet can be used to achieve speeds in excess of Mach 18. The scramjet allows the TAV to approach orbital parameters. For higher speeds (up to Mach 25, i. e., orbital velocity) and higher altitudes, rocket engines are used for exoatmospheric flight and to achieve orbital velocities. Rockets will be used for on-orbit maneuvering and to accomplish de-orbit.

The slush hydrogen fuel used by all TAV engines is both high energy and heat absorbing. The fuel is also employed as a

coolant and is circulated throughout the TAV, by turbopumps (active cooling), to reach areas such as the nose and engines that experience the highest level of heat flux. Hence, the slush hydrogen fuel is referred to as a cryogenic propellant.

Thermal loading of the TAV's surfaces is expected to be extreme. Temperatures in excess of 2,000 ^{o}F are expected to be encountered over large areas of the TAV's surface, while the wing leading edges might experience temperatures greater than 4,000 ^{o}F. Higher temperatures, such as might be generated by endoatmospheric shock wave interactions, may exceed 5,000 ^{o}F. It has been estimated that the heat load experienced by the TAV nozzle due to engine exhaust, for example, might reach as high as 180,000 BTU/sec. Reducing these temperatures will require highly effective use of insulation (e. g., isolation of the fuel storage tanks), passive cooling/heat pipe/exchanger (e. g., for large fuselage surfaces) and active cooling (e. g., for the TAV nose, and wing leading edges and for the exhaust nozzle) technologies. Additionally, utilizing the heated hydrogen in the combustion engines achieves a thrust improvement.

Advanced strong, lightweight, heat resisting/dissipating skin materials will be capable of withstanding the extreme and repeated cycles of hot and cold temperature (from -485 to +2500 [and higher] degrees F) and shock waves encountered over the flight regime. TAV performance capabilities are based on integrated, interdependent sub-/super-/hypersonic engines and platform aerodynamics, skin and structural materials, propulsion,

and flight control systems. One major example of the level of integration represented by the TAV is the relationship between the vehicle and its propulsion system. The portion of the TAV underbody forward of the engine inlet performs precompression of the entering airstream while the underbody aft of the engine forms part of the exhaust nozzle.

The TAV is capable of either orbital insertion or sub-orbital (endoatmospheric), hypersonic (above Mach 6) flight at altitudes as high as 350,000 feet, allowing it to perform sustained trans-hemispheric missions. It is capable of accomplishing single-stage-to-orbit (SSTO), direct ascent to low Earth orbit, maneuvering while on orbit, de-orbiting, and hypersonic flight within the atmosphere. Orbits may be polar, equatorial, or any intermediate azimuth. All-azimuth flight capability assures access to all required orbits and greatly expands the conventional "launch windows" which constrain purely ballistic space transportation concepts. Suborbital missions include hypersonic cruise within the upper atmosphere.

Takeoff and landing are accomplished horizontally from conventional runways (of length greater than 11,500 feet), reducing the required infrastucture in terms of both facilities and personnel. All TAV operational bases would require capacity for liquid/slush (partially frozen) hydrogen production, pumping, sensing, and storage; TAV fueling carts/cells; TAV hangers/vehicle shelters; P/L preparation, inspection, handling, and mating; air operations and mission control (flight preparations.

communications, and support); aircraft-like TAV maintenance; subsystem specialty shops; engine run-up and test cells; mission planning and crew training/mission rehearsal facilities, and post-flight fuel disposal and TAV safing areas. Landings may be made in either a powered or unpowered (glide) configuration. The TAV is capable of performing self-ferry. It can fly from one base to another, takeoff from one base and recover to a second one and return to the base of origin, if required. Engines will have a re-start capability and the TAV will be capable of performing a "go-around" during a runway approach. Conventional airbase recovery, manned operations, and a flyable aircraft all contribute to enhanced safety in the event of a major on-board malfunction.

It is global in range. Orbital parameters include high hypersonic velocity while suborbital flight profiles are executed at low to medium hypersonic speeds. It is highly responsive to mission tasking. P/Ls are pre-prepared and "containerized" for rapid loading into the TAV P/L bay. P/L interfaces to the TAV are either standardized (e. g., Mux bus) or P/L specific (i. e., unique airborne support equipment). Containerization and provision of robust standard P/L/TAV interfaces obviate the need to modify the TAV P/L bay during mission preparation, greatly enhancing availability and reducing turnaround time and complexity. (Typical TAV turnaround is expected to take approximately five days.) The P/L interfaces with the container may be as complex and specialized as required for the mission;

the interface between the container and the TAV is (in general) constant. Containers are, then, readily interchangeable across TAVs. Mission flexibility can be further enhanced by onloading a combination of P/Ls which tailor TAV capabilities to specific mission requirements.

While mated to the TAV, P/Ls are serviced (through the container interfaces) by the TAV. P/L servicing includes mechanical, electrical, avionics, environmental, and operations support. The P/L container is mechanically attached to the TAV within the P/L bay. Access is provided for installation, deployment/retrieval, and/or operation (which may require extra-vehicular activity, EVA). The TAV serves as the P/L power source during installation, ground operations (including checkout), ascent, on-orbit operation, and descent. The avionics interfaces may include provision for ground-based or on-board P/L operation, status monitoring, guidance/control updates, data recording, and data transmission (possibly including encryption/decryption). The P/L may have specific heating/cooling requirements to be satisfied by the TAV. It may require purging and contamination control measures. It may require replenishment of liquid or gaseous consumables or, conversely, may require venting of superfluous liquids or gases. The P/L operation may require direct, (visual) viewing by the TAV crew and/or video recording of P/L deployment or operation for immediate transmission to a ground station or for post-mission analysis. Although most TAV P/L services are standardized, some P/Ls may have unique support

requirements which must be satisfied. Some mission-specific P/L services will therefore be required.

P/Ls are either deployed during the mission (e. g., orbital insertion) or remain with the TAV for the duration of the mission (e. g., sortie P/Ls). Multiple P/Ls, representing same or dissimilar missions, are prepared in parallel and mission-specific loading is accomplished in TBD hours. The TAV is highly responsive to operational tasking. A missionized TAV, sitting alert, can takeoff in TBD minutes. Because of mission-oriented P/Ls and general design capabilities, the TAV is capable of quick turnarounds, either for the same (i. e., immediately previous) mission type or for a new one, in TBD hours. Launch windows are relatively unrestricted, allowing for flexibility in launch times and azimuths. System robustness (availability rates) and turnarounds are enhanced by an extensive automated subsystem diagnostic capability which reduces maintenance/repair times.

The TAV is reusable. The only resource expended is the hydrogen fuel. Several hundred missions may be accomplished before a major overhaul is required.

The TAV can adjust altitude, Mach, and heading during the course of a mission. Selection of inclination, coupled with maneuverability, can assure that the mission does not overfly specified geopolitical boundaries, can avoid (or minimize) exposure to possible ground-based threats, and can reach virtually any ground-based or air-/space-borne target within a matter of hours. Maneuverability and orbital/suborbital endurance provide

a capability for target revisit. Launch flexibility (times, inclinations, etc.) and platform maneuverability also support unpredictability of vehicle profile in terms of heading, ground track, altitude, and speed. The TAV's flight regime, coupled with maneuverability and track/flight path unpredictability, provide a high degree of survivability. Flexibility is supported by P/L assignment and the presence of a two-man crew. Alternate mission recovery paths, achieved by cross-range flight maneuvers, support both flexibility in TAV operations and safety-of-flight (in the event of a mission abort).

P/Ls are in the small to medium weight range (10 to 30 thousand pounds) and afford the tasking authority with a great deal of flexibility as to mission objectives. P/Ls may include a combination of mission-specific avionics (including sensors) and weapons.

The TAV system maintains connectivity (communications) with primary command and control centers (e. g., Space Command Center), primary operations centers, and component command centers (Air Combat Command [formerly elements of SAC and TAC], AF Space Operations Center, Navy). Specific component command centers will depend on mission type(s). Connectivity between TAV and centers will rely on the MILSTAR (Military Tactical, Strategic and Relay) and TDRSS (Tracking and Data Relay Satellite System) capabilities, augmented by the Defense Satellite Communications System (DSCS). Navigation accuracy will be maintained through a secure (Global Positioning System) GPS link.

SYSTEM AVIONICS FUNCTIONS

The TAV is similar to a combat aircraft with regard to the functions supported by avionics capabilities. Reliability is achieved by robustness of avionics design and redundancy. A "Fail-Operational, Fail-Operational, Fail-Soft" degraded mode of operation design policy is achieved through redundant subsystems, alternative means of accomplishing mission-critical functions (backup and degraded modes of operation), and a distributed computer architecture.

The TAV concept of operations is based on a manned system. The crew provides a major element of system flexibility by providing the on-board control necessary to make the platform "recallable," to implement weapon commit/withhold decisions, to perform EVAs for space asset recovery/repair and personnel rescue missions, to operate mission P/Ls, to monitor the deployment of P/Ls, to respond to mission plan updates, and to respond to unplanned events. The crew implements flight control commands generated by the Flight Control System (FCS) based on established flight rules, monitors TAV subsystem performance and mission P/L operation, monitors the mission plan execution, conducts routine and mission-specific duties in accordance with standard operating and special procedures and checklists, responds to unplanned events in accordance with established tactical doctrine, and maintains communications with appropriate command centers.

In the following portion of the TAV system description, each of the major avionics (or avionics-related) subsystems is identified and functionally defined. A crew-centered perspective

is emphasized in these descriptions.

Mission Planning: Ground-based mission planning supports rapid preparation of mission-specific data. Data bases (including DOB [defensive order of battle], TAV capabilities [e. g., fuel burn rates], and P/L-driven requirements) are exploited in generating the specific mission plan. Mission data include takeoff inclination, Mach number/fuel burn schedule, planned headings, planned altitudes, threat types/locations, communications satellite network availability schedules, and P/L/target-specific mission events. The mission materials are transferred to the TAV by means of magnetic media.

Mission Briefing/Rehearsal: Mission materials are loaded into the Weapon System Trainer (WST) and mission briefing is conducted in this training device while preflight (fueling) of the TAV is in progress.

Trajectory Management Subsystems:

Vehicle State Sensing: Attitude (pitch, roll, yaw), attitude rates, altitude, heading, and Mach number are calibrated. Attitude and heading data are provided by the INS. Altitude may be based on a GPS satellite system. A combination of radar altimeter and astroinertial systems may be used as back-up. Mach number is computed from altitude and fuel burn data.

Flight Instrumentation: (See Crew/Vehicle Interface, [C/VI], below).

Vehicle/Flight Control: Control of TAV altitude, attitude, Mach, and heading. A fly-by-wire FCS is utilized. (The TAV is

aerodynamically sensitive to small changes in vehicle configuration and computer-assisted FCS offloads the crew from the burden of repeated fine control input corrections.) The TAV exploits active flight control to reduce aerodynamic flutter and to improve ride quality. A closed-loop, multi-input/multi-output control law feedback system dynamically recovers flutter dynamic pressure lost due to aerodynamic heating and minimizes turbulence/gust loading-induced vibration experienced at the crew station. The FCS includes the flight control computer and algorithms, together with the navigation sensors, required to support trajectory/vehicle state control. The FCS generates guidance solutions for requested trajectories/state changes; monitors flight path errors (by comparing actual vehicle state [sensed] against computed/predicted trajectory); and performs a reoptimization (replan) of the guidance solution based on flight path errors, crew direction/overrides, and/or changes in mission constraints. It also monitors actual fuel consumption, compares it against the mission fuel schedule, predicts rest-of-mission fuel consumption, and calculates expected time of arrival (ETA) to each mission objective. The FCS supports safety of flight by calculating abort trajectories to achieve at least two alternate recovery bases under powered or unpowered flight conditions.

Data from the FCS is integrated with other TAV and mission data load (MDL) information and presented to the crewmembers on the vertical situation display (VSD) and horizontal situation display (HSD). The VSD serves as the primary flight management

information source while the HSD serves as the central reference to the preplanned mission activities. Together, these format screens serve to provide a high level of situational awareness to the TAV's aircrew. These formats are complemented by the "Self-Help" subsystem (described below) format which provides status information regarding all "ownship" subsystems.

Major functions of the FCS are orbital transfer maneuver, ascent-to-orbit, rendezvous, station-keeping (in a preplanned orbit), targeting, de-orbiting/re-entry, and return-to-base (RTB). The FCS is autonomous and does not rely on ground-based trajectory planning. The FCS provides the TAV with an adaptive guidance capability. It can correct for in-flight perturbations experienced by the vehicle, respond to differences between P/L -specific orbital placement requirements, support trans-orbital maneuvering, and optimize fuel expenditures. It carries out these functions by sensing the current vehicle state, sensing the environmental conditions, determining the desired vehicle state, computing an optimal trajectory to achieve that state, and providing flight control commands to the TAV crew. All of the functions are carried out with reference to the MDL, a data base of mission plan, TAV performance, and P/L-specific requirements information.

Air Data System: Sensing and processing subsystems. Data are used to determine dynamic pressure, to adjust engine cycles, and to refine endoatmospheric speed computations.

Situational Awareness: TAV mission plan (altitude, Mach, timing

[ETA, TTG], [backup] navigation fixpoints, targets, launch/recovery/abort bases, geopolitical boundaries, "keep out areas,"), DOB.

Electronic Support Measures (ESM):

Threat Detection, Location and Ranging: A combat aircraft-like radar warning receiver system is used to detect, characterize and locate active emitters (EOB, emitter order of battle). EOB activities are monitored and correlated against data base DOB. An appropriate response is made to counteract any threat activities which impact mission accomplishment.

Electronic Warfare (EW): Electronic countermeasures may be employed to defeat threat capabilities.

Penetration Aids: Expendable countermeasures including chaff and advanced penetration aids (perhaps including decoys) may be employed to defeat specific threat systems.

Communications/Navigation/Identification (CNI):

Communications: Although the TAV carries out autonomous operations, it is capable of two-way voice, text, imagery (P/L sensors, TAV video, etc.), and data (telemetry) transmission, either encrypted or in clear, with the primary operations control, the component command center (mission specific), and with other command and control activities (as required). Connectivity will facilitate real-time operations, provide command authorities with additional flexibility to apply the TAV fleet as a force element, and provide for additional capabilities in the event of in-flight emergencies.

The MILSTAR constellation of communications satellites serves as the primary TAV communications network. The TDRSS serves to augment this network. The DSCS may also serve as a direct communications link or as a relay between other nodes and links in the communications network. The TAV assures appropriate antenna pointing, executes a "handshake" protocol with the link to obtain a suitable channel, and maintains the link (switching satellites, if required) throughout the course of the mission.

Navigation: The GPS satellite system serves as the primary navigation system. The TAV employs a GPS antenna, establishes connectivity with the GPS satellite, accomplishes a "handshake" protocol to obtain a secure link, and maintains that link throughout the course of the mission. An inertial navigation system (INS) may be employed as an (much less accurate) autonomous position reference. A synthetic aperture radar (SAR) ground map capability may be employed to obtain an intermediate level of positional accuracy by exploiting fixtaking points of known position (latitude/longitude/elevation) in updating the INS.

Identification: The TAV is capable of interrogating and classifying a variety of IFF transponder-equipped platforms.

Self-Help: An embedded, automated capability to perform subsystem status/health monitoring. It includes near-continuous subsystem performance data acquisition (exploiting bit-in-test [BIT]/self test [ST] design capabilities), monitoring and display of own-ship subsystem status, and provides a real-time support capability to the TAV crew. The Self-Help capability supports

the crew in performing diagnostics on subsystem problems/failures, responding to WCA annunciations, reconfiguration of subsystems for alternate/degraded modes of operation, and achieving/maintaining situational awareness regarding ownship status and capabilities. The WCA MPD secondary format screen embodies a management-by-exception concept; a WCA annunciation appears on all MPD screens in the event of a failure or out-of-nominal subsystem condition. The crewmember responds by either acknowledging the alert message or by activating the primary WCA MPD display format screen to obtain additional information.

WCA annunciations are color coded to convey the severity of the subsystem problem and the urgency of the required crewmember response. Advisories, the lowest level of severity, are color coded in yellow. Caution messages, generated by failure of a non-critical subsystem, an out-of-nominal condition in a mission-critical subsystem, or by any condition in which a degraded mode of operation has automatically been adopted without loss of mission capability, are coded in orange. Warning annunciations and messages, the most severe/urgent level, are coded in red. Caution and warning events are accompanied by an auditory alerting tone and require a response on the part of the crewmember. The required response to a warning message is for the crew to invoke the Self Help Subsystem MPD format screen.

The Self-Help Subsystem will automatically reconfigure failing or failed subsystems in cases where the degraded mode adopted will result in no loss in mission capability or TAV

effectiveness. This reconfiguration is conducted by the rule-based, artificial intelligence component of the Subsystem. Since these rules embody established standard operating procedures, crew consent to the reconfiguration action is implicit and only an advisory message would be presented at the C/VI.

The Self-Help Subsystem is also a major factor in reducing TAV turnaround time. The on-board diagnostics/health monitoring facility aids maintenance personnel in performing fault detection, fault isolation, and scheduled/unscheduled maintenance. The Self-Help system support to trouble shooting, as well as basic design features, affords a next day launch after failure repair capability.

The Self-Help Subsystem may support troubleshooting of malfunctioning P/Ls. BIT data from the P/L is passed /across the P/L interface and is available on the Mux bus. In the event of a P/L malfunction, the crew can employ the Self-Help capabilities to assist in restoring P/L functioning (cycling modes, reloading data, etc.).

<u>Crew/Vehicle Interface (C/VI) Systems</u>: Access to the crew station compartment is through the wheel well. The cockpit is located adjacent to and forward of the P/L bay. The TAV has a two-place, side-by-side, flight station. Four, large, color cathode ray tube multi-purpose displays (MPDs) are used for information display and serve as the primary cockpit instrumentation. A "paperless" or "glass" cockpit concept provides all mission materials (checklists, flight charts,

navigation aids, communications schedules, procedures, system/P/L/mission reference data, primary and alternate recovery base data, etc.) in softcopy format. (Hardcopy materials [i. e., paper format] are carried stowed only for backup.)

Dedicated Master Mode selection controls (panel-mounted pushbuttons) facilitate the rapid (re)configuration of the C/VI, based on the priorities of each mission phase. Additional display format controls (bezel-mounted pushbuttons) allow the crewmembers to "tailor" the configuration to meet their individual preferences and/or prepare for and respond to any special mission phase requirements.

It is assumed that, with the two-man crew, one crewmember will always be the pilot "in command." That is, this crewmember will always have primary responsibility for all flight control/trajectory management and safety-of-flight aspects of the current mission phase. To support this C/VI concept,a "super-level" Master Mode control will serve to select either of the two crew positions as responsible for flight control; in essence, this will serve as a "take charge" C/VI function. This concept will also be reflected in the response of the selected crew station to a Master Mode input. The C/VI at the selected station will always include the primary flight control displays.

Environmental Control System (ECS): The crew compartment is maintained so as to provide a "shirtsleeve" environment. Cabin/compartment (ambient) temperature, pressure, gaseous composition, humidity, and lighting are automatically controlled (with

manual override) to provide this environment. The crew compartment provides protection from external environmental stressors.

Controls and Displays: Flight, instrument, sensor, and data displays to support trajectory management; subsystem operation, moding, and reconfiguration; system/subsystem status monitoring; P/L operation or deployment; and vehicle control.

The primary flight instrument display is the VSD. The VSD presents both planned (nominal) and actual (sensed) attitude, angle of attack (alpha), trajectory, vertical velocity, Mach number, altitude, heading/inclination, and rate of climb information. The nominal trajectory information is derived from the trajectory manager which computes and continuously updates optimal flight paths and mission schedules for accomplishing the planned mission.

The VSD is complemented by a HSD format screen which depicts current ground track, projected ground track (including next orbit), timing (including time-to-go [TTG] to next mission event/action point), target, and other geographically referenced mission data. The combination of HSD and VSD provides the TAV crewmember with his primary means of obtaining situational awareness with respect to the planned mission and to progression through that mission.

In addition to the VSD and HSD, a Flight Control Subsystem MPD format screen affords the crew the capability to intervene (override) the functioning of the automated flight control and trajectory management subsystems. For example, TAV control

surface configurations may be adjusted, mission phase transition points may be adjusted based on updated navigation and guidance data received during a flight, and safety-of-flight constraints may be applied.

Flight controls, located at each crew position, include: Side Stick Controller: Controls TAV attitude (pitch and roll). Split Segment Throttle Control: The Master segment controls all operating engines. The Auxiliary segment is employed in responding to engine-out anomalies. (The Auxiliary throttle is selected/activated by means of a Throttle Select button located on the Control Stick. When activated, the Auxiliary throttle automatically takes control of the unstarted engine(s), leaving the Master throttle in control of the good engines.) Flight instrument data are presented on the MPDs. The Approach/Landing page of the Flight Data display format, for example, presents airspeed, altitude, pitch angle, vertical velocity, angle of attack, and dynamic pressure (q). (q may range from 0 to 2000 pounds per square foot). The Thermal Management display format depicts the distribution of thermal flux (skin and engine-internal) being experienced by the TAV and the efficiency of heat dissipation, active cooling, and heat piping in managing these loads.

External Visual: Direct and indirect (sensor-mediated) contact with the outside world is provided to support vehicle control and crew situational awareness requirements under visual meteorological conditions (VMC).

Subsystems: In addition to the subsystems identified above, the TAV has:

P/L Interface: All P/L monitoring and servicing functions are supported by this subsystem. The containerized P/L is installed in the TAV P/L bay. The P/L interface provides the mechanical mating and is the interconnection between the TAV and the P/L container. P/L status data are passed from the container to the TAV. The TAV provides power, environmental control, and replenishment of P/L consumables across the P/L interface. P/L servicing requirements are identified in an on-board data base. During P/L operations, imagery or other sensor data, and data from space experiments are passed to the TAV for recording and/or transmission. The P/L interface MPD format screen provides situational awareness information to the TAV crew regarding P/L status and operation. For example, a P/L may be capable of several operational modes: OFF, STANDBY, MODE A, MODE B, etc. The P/L interface screen allows the crew to manually change these modes (although normal P/L operations would be based on an automated mode control capability). Guidance and control updates, received by the TAV during the flight, can be passed to the P/L to modify the P/L-internal or MDL-provided pointing commands, operating schedules (modes, times), etc.

Sensors: The TAV will have a rendezvous radar to assist the crew in accomplishing orbital matching and closure with space assets. Surveillance mission sensors (e. g., synthetic aperture radar and/or electro-optical imaging systems) may be organic to the TAV

or may by provided by means of a standard surveillance P/L.

Signal Processing and Data Distribution: Multiple flight control and signal processors (computers), together with mass data storage capabilites, and interconnected by a redundant high speed data bus.

Recording and Telemetry: Sensor imagery (organic or P/L), TAV performance data (self-help subsystem), and mission data are recorded for delayed playback (transmission/telemetry) to appropriate ground station and/or for use in post-mission debriefing.

Thermal Management: The TAV employs a primarily active cooling system. The hydrogen fuel is injected into each engine as a film coolant, protecting critical engine components from the superheated airflow. The engine cowl leading edge is subjected to the most extreme external heating due to the interaction of the bow shock wave and local shock wave at high Mach numbers. A heat pipe approach is used to cool this maximum heat flux location. The heating rate and heat load are monitored at the TAV nose, wing leading edges, and along the aircraft's bottom centerline.

Electrical Generation and Distribution: Onboard electrical power generation and distribution system.

Fuel and CG Management: All propellants are carried internally. Onboard fuel storage, internal fuel transfer (pumping), and burn scheduling. Center of gravity (CG) management. (CG position changes will affect aircraft stability, flight control responses, aerodynamics, overall handling qualities, and effective engine thrust.)

Pneumatics and Hydraulics: Fluids required for activation of mechanical flight control surfaces, landing gear retrieval/deployment, etc. The associated MPD format screen provides loading, pressurization, and transfer status information and affords subsystem control.

Engines: Engine operating parameters (inlet, combustion, nozzle operational settings) for ramjet/scramjet modules and orbital maneuvering rocket motors. Key engine operating parameters include inlet temperature and pressure (including shock wave transients), fuel temperature, fuel injector setting, combustor temperature, and nozzle temperature and pressure. Engine body temperature, including the active cooling system jacket temperature, is also monitored.

Propulsion flows: Airflows around inlets, nozzles, and combusters (where fuel and air are mixed and ignited).

Warnings, cautions, and advisories (WCA): Including both visual display and auditory annunciator tones.

CONCEPT MAPS

This subsection presents the Concept Map depictions of the baseline TAV system. Figure 7 presents an overview of the organization of the Concept Maps. The represe ation is centered about an operationally-ready TAV system. Readiness refers to the capability to perform a tasked <u>mission</u>. Readiness is achieved through the preparation of a flight-ready <u>TAV</u>, by the creation of a <u>mission data load</u>, by the mating of a mission <u>payload</u> to the

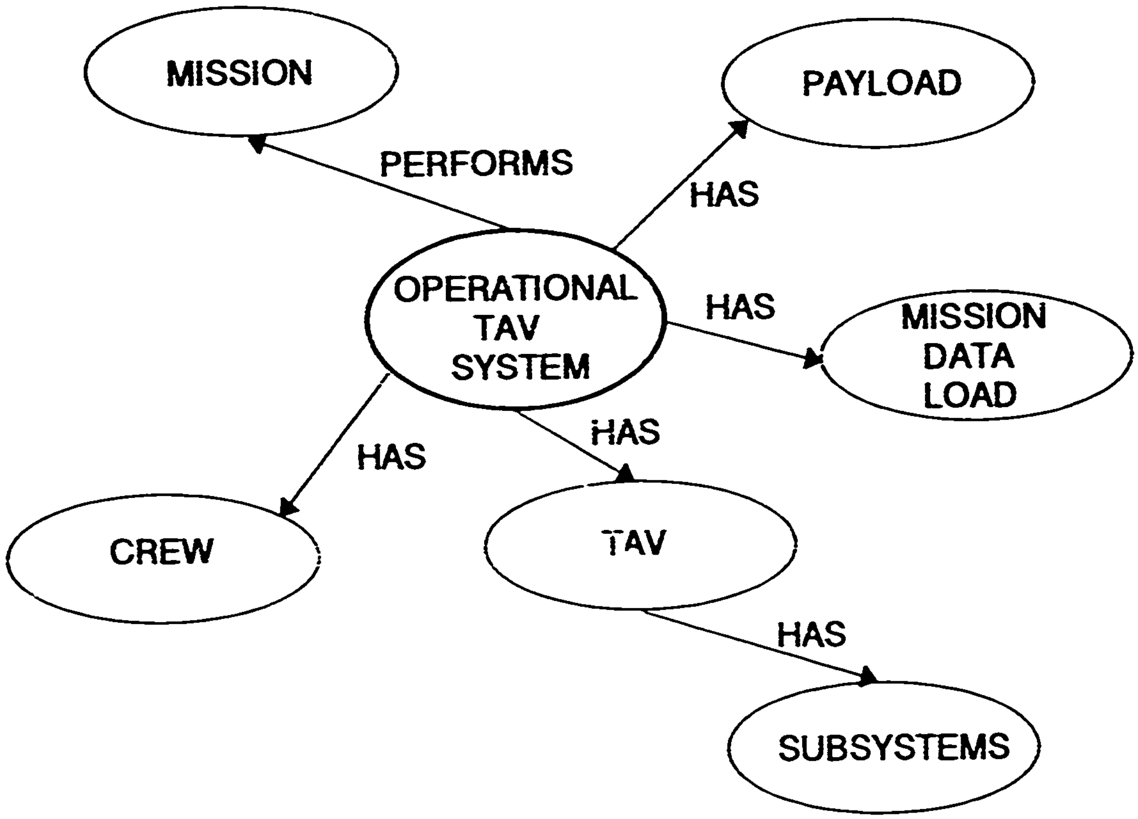

Figure 7. Overview of TAV System Concept Maps

TAV vehicle, by the availability of a trained and briefed crew, and by the utilization of avionics subsystems.

Figure 8 is a depiction of the missions which might be performed by an operational TAV system. Figure 9 (a through e) presents a decomposition of the measures of effectiveness (MOEs) which might be associated with the operational capability. (Measures of effectiveness and performance are discussed in greater detail in Section V.)

Figure 10 (a and b) presents the concepts and relationships associated with the TAV mission P/L. It also depicts the tie between the TAV and the P/L, the P/L interface.

Figure 11 is an overview of the TAV avionics subsystems. Each subsystem is further decomposed below.

Figure 12 (a through d) presents the TAV system concepts which relate to the crew and the C/VI. The map incorporates the TAV controls and displays and emphasizes crew situational awareness.

Figure 13 (a through c) presents the communication, navigation, and identification subsystems concept maps. It is implicit in these concept maps that all subsystems are interconnected through the means of the high speed Mux bus. Figure 14 is the concept map of the TAV's ESM subsystem.

Figure 15 (a and b) depicts the FCS. The trajectory management subsystem is shown as integral to the FCS.

Figure 16 is the concept map for the "Self-Help" subsystem. Again, the tie to all other avionics is implied.

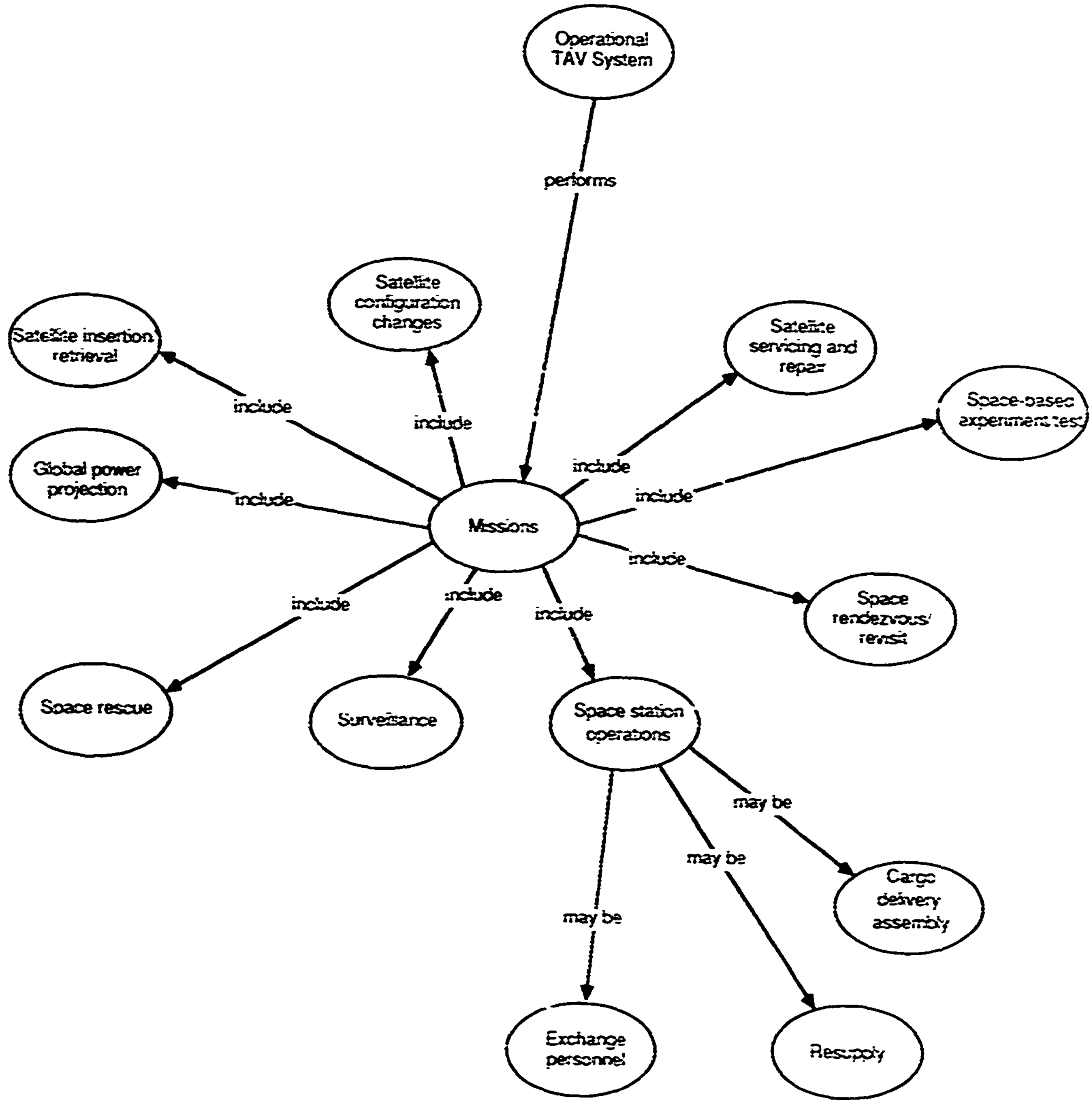

Figure 8. Concept Map of TAV Missions

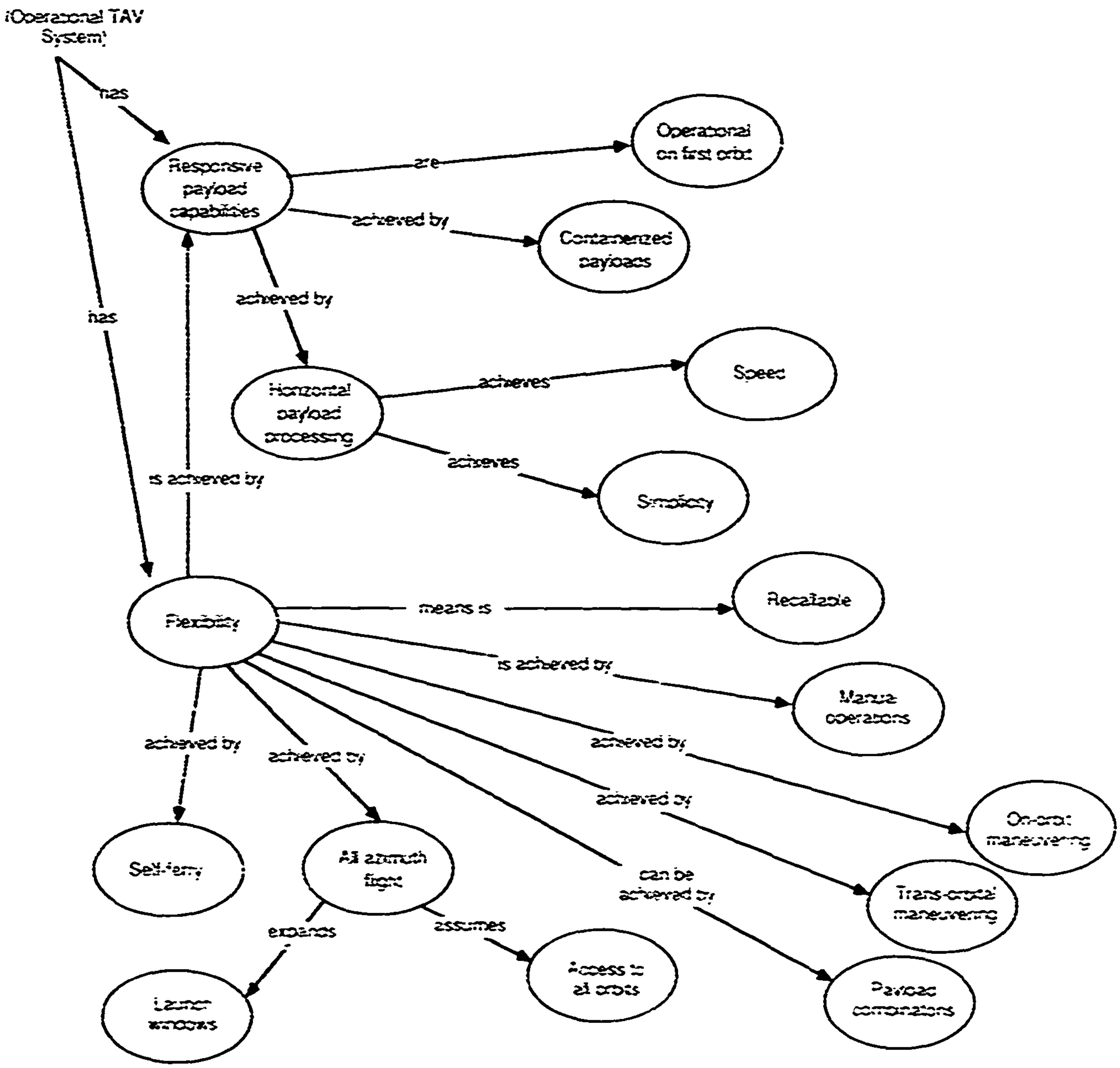

Figure 9a. Concept Map of Operational TAV Measures of Effectiveness

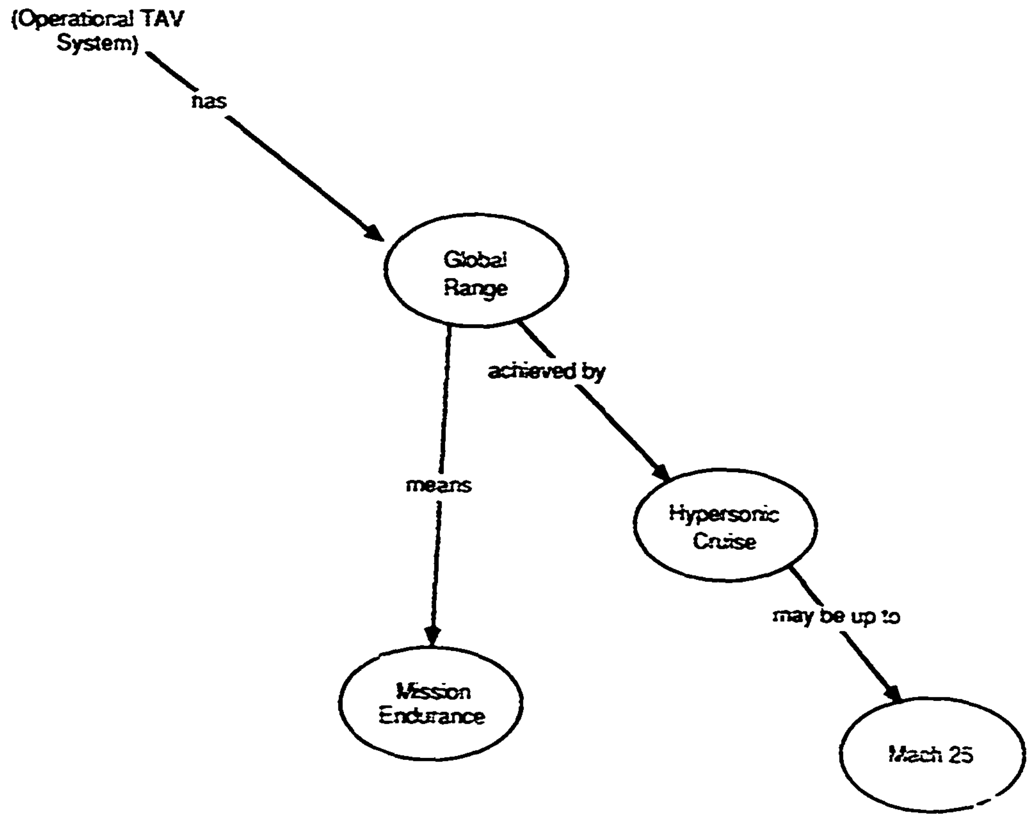

Figure 9b. Concept Map of Operational TAV Measures of Effectiveness

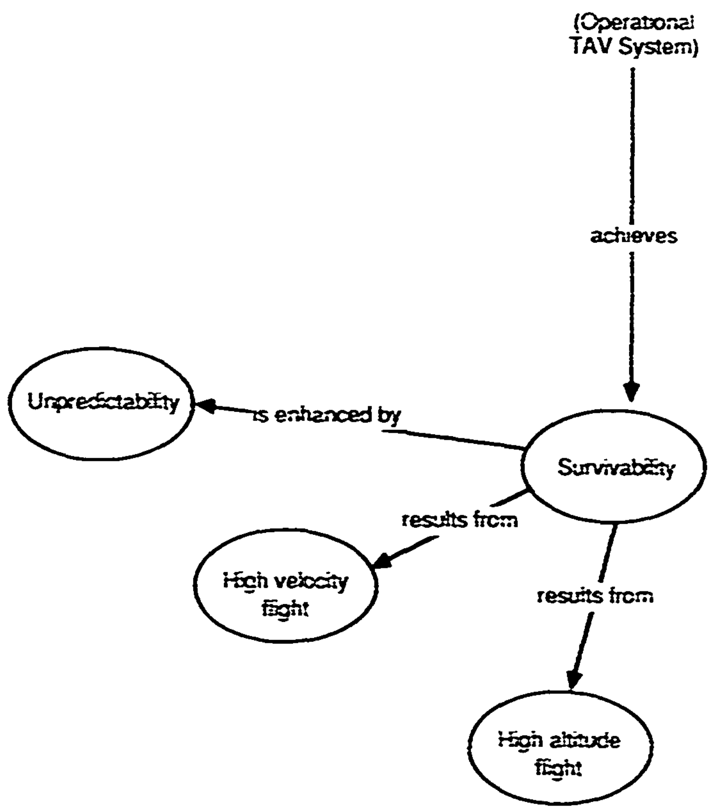

Figure 9c. Concept Map of Operational TAV Measures of Effectiveness

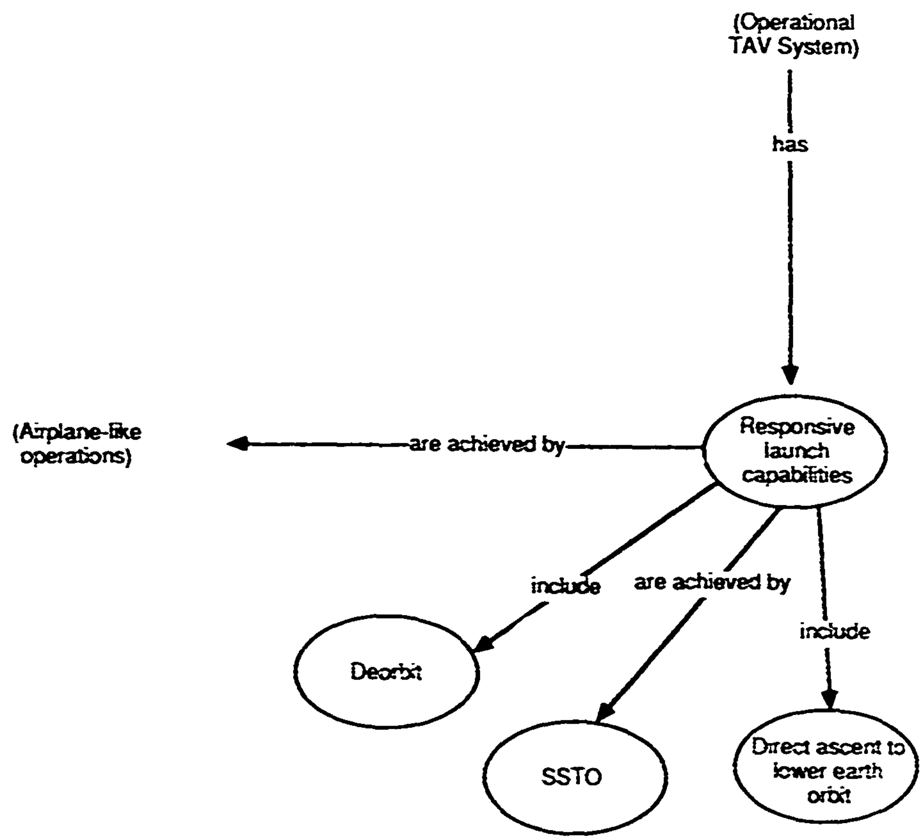

Figure 9d. Concept Map of Operational TAV Measures of Effectiveness

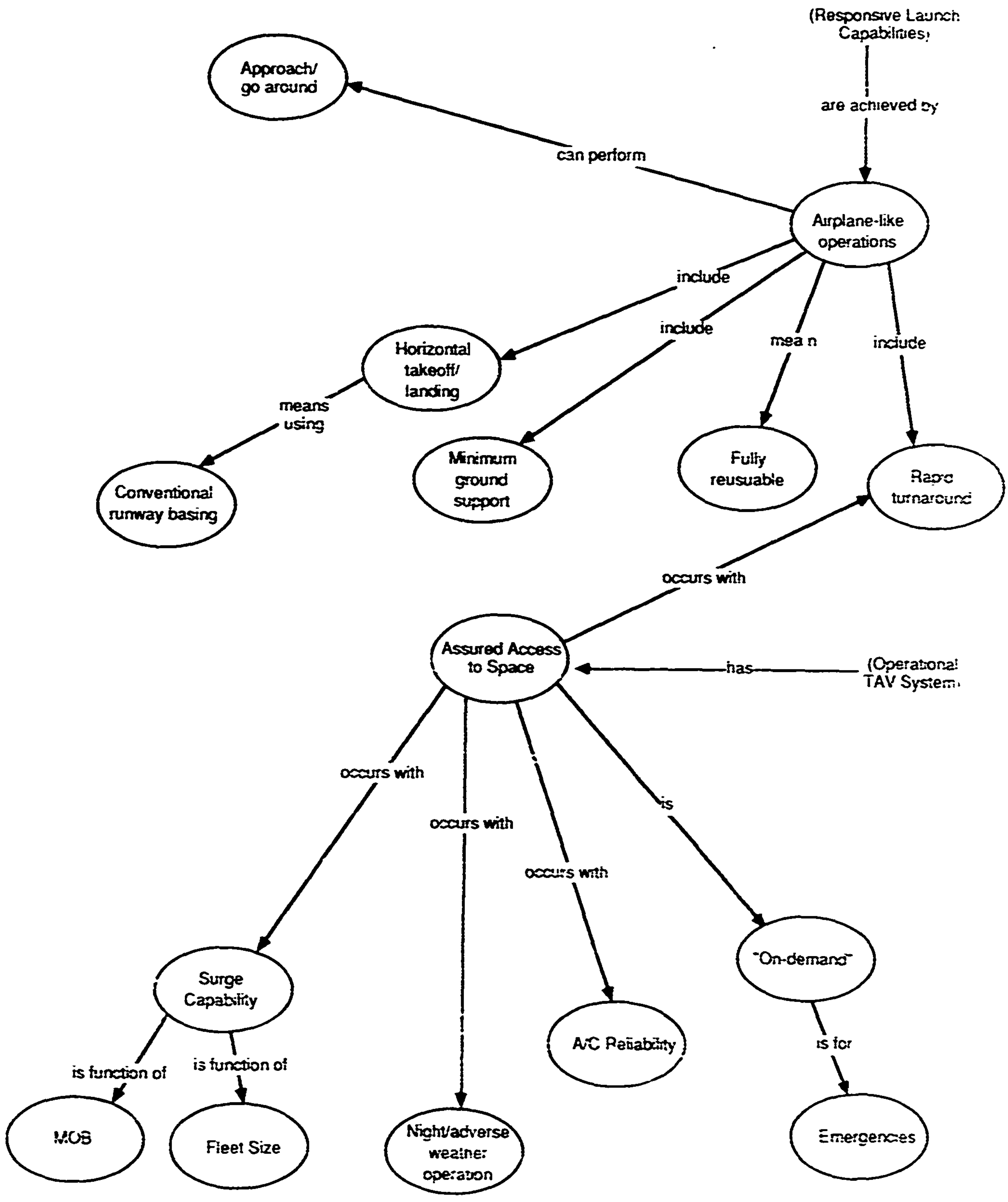

Figure 9e. Concept Map of Operational TAV Measures of Effectiveness

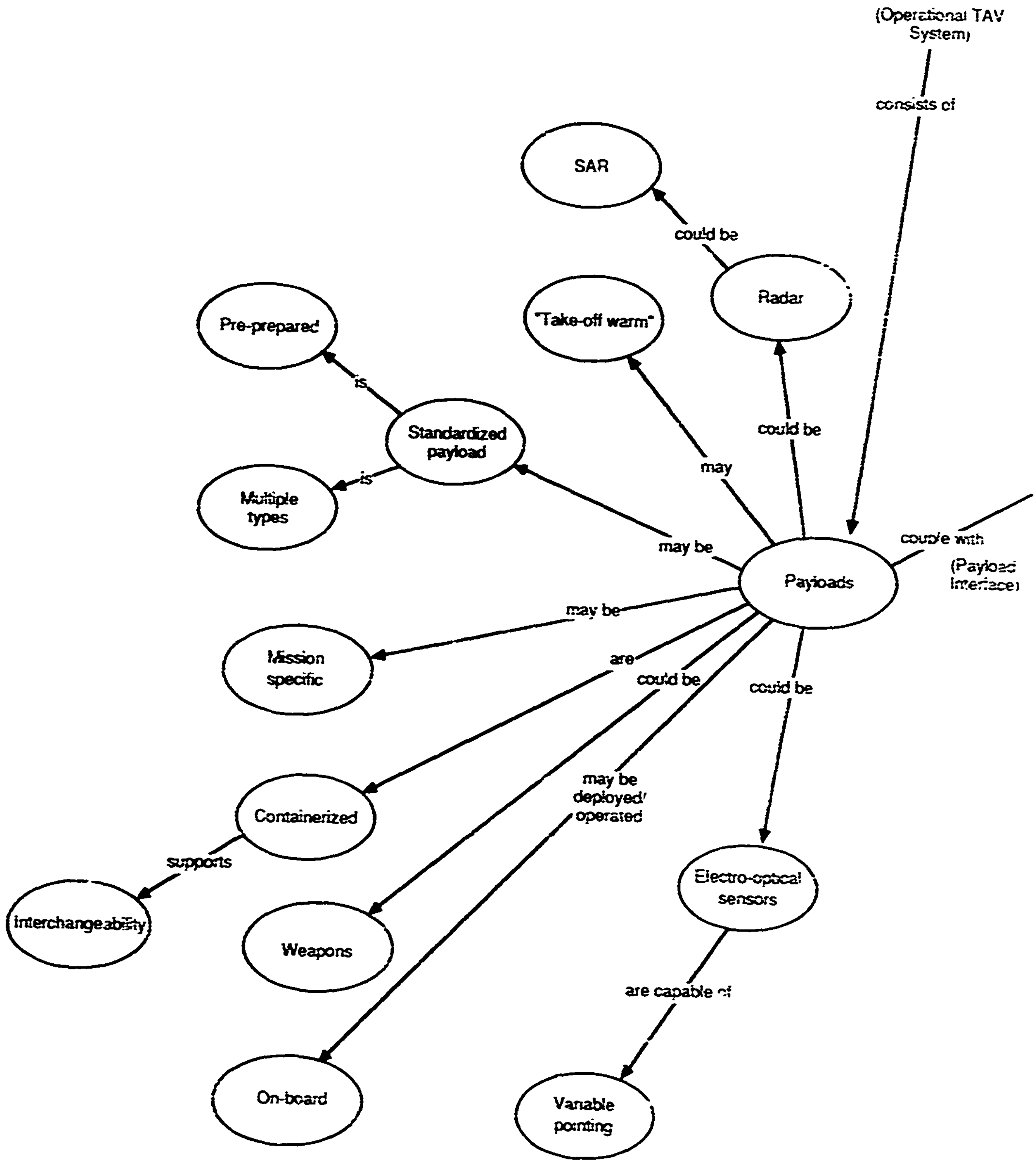

Figure 10a. Map of TAV Payload Concept

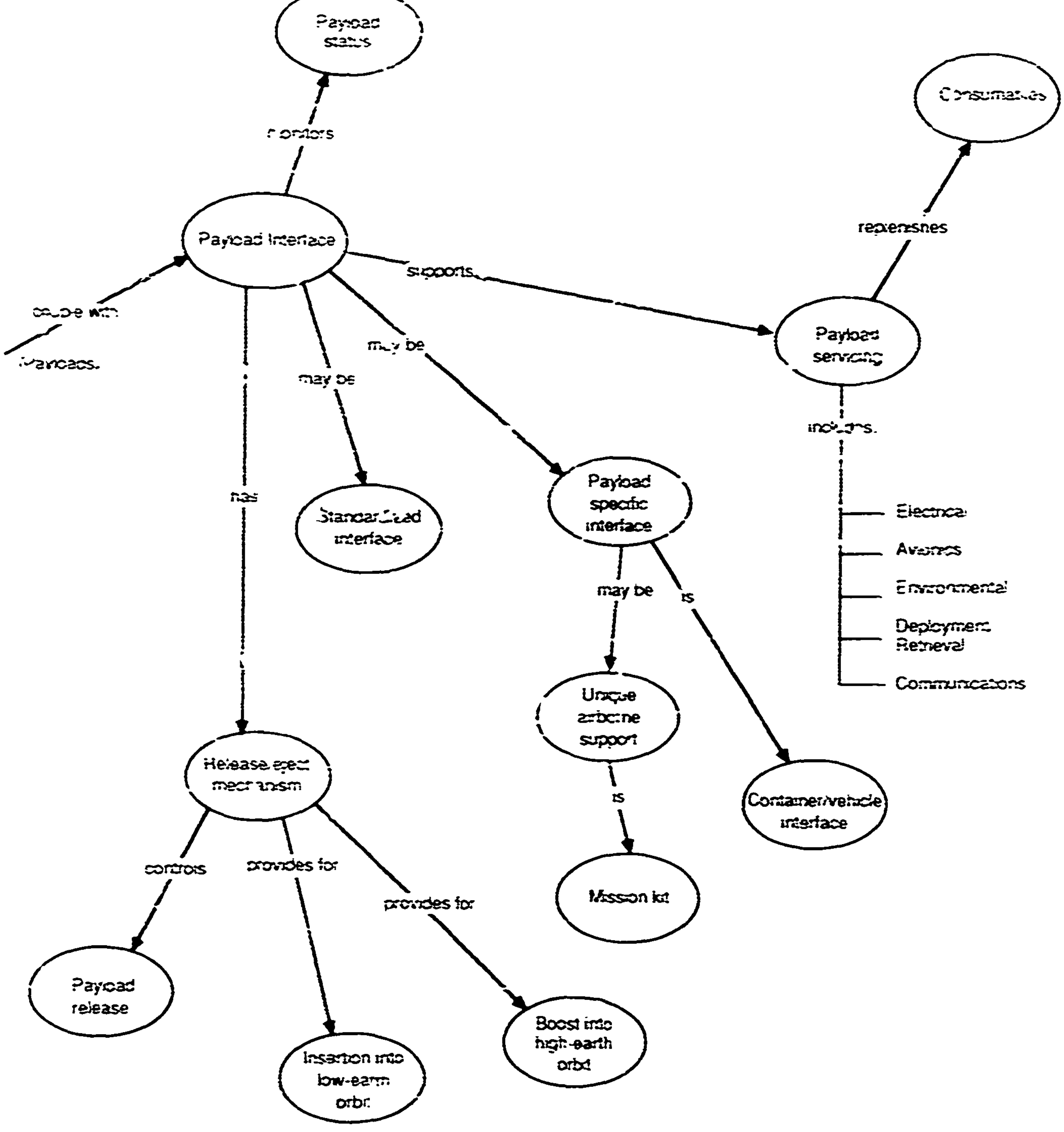

Figure 10b. Map of TAV Payload Concept

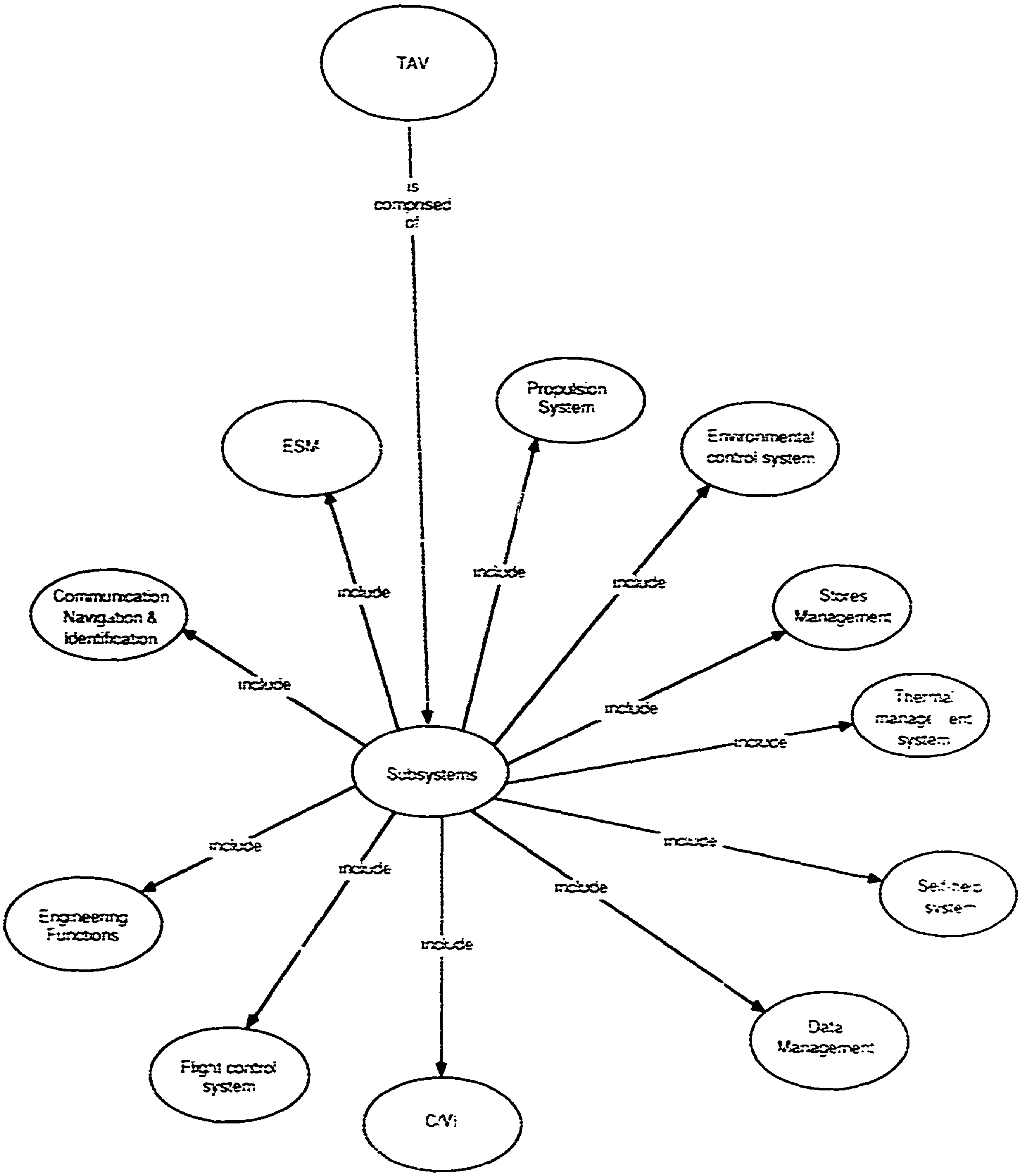

Figure 11. Concept Map of TAV Subsystems

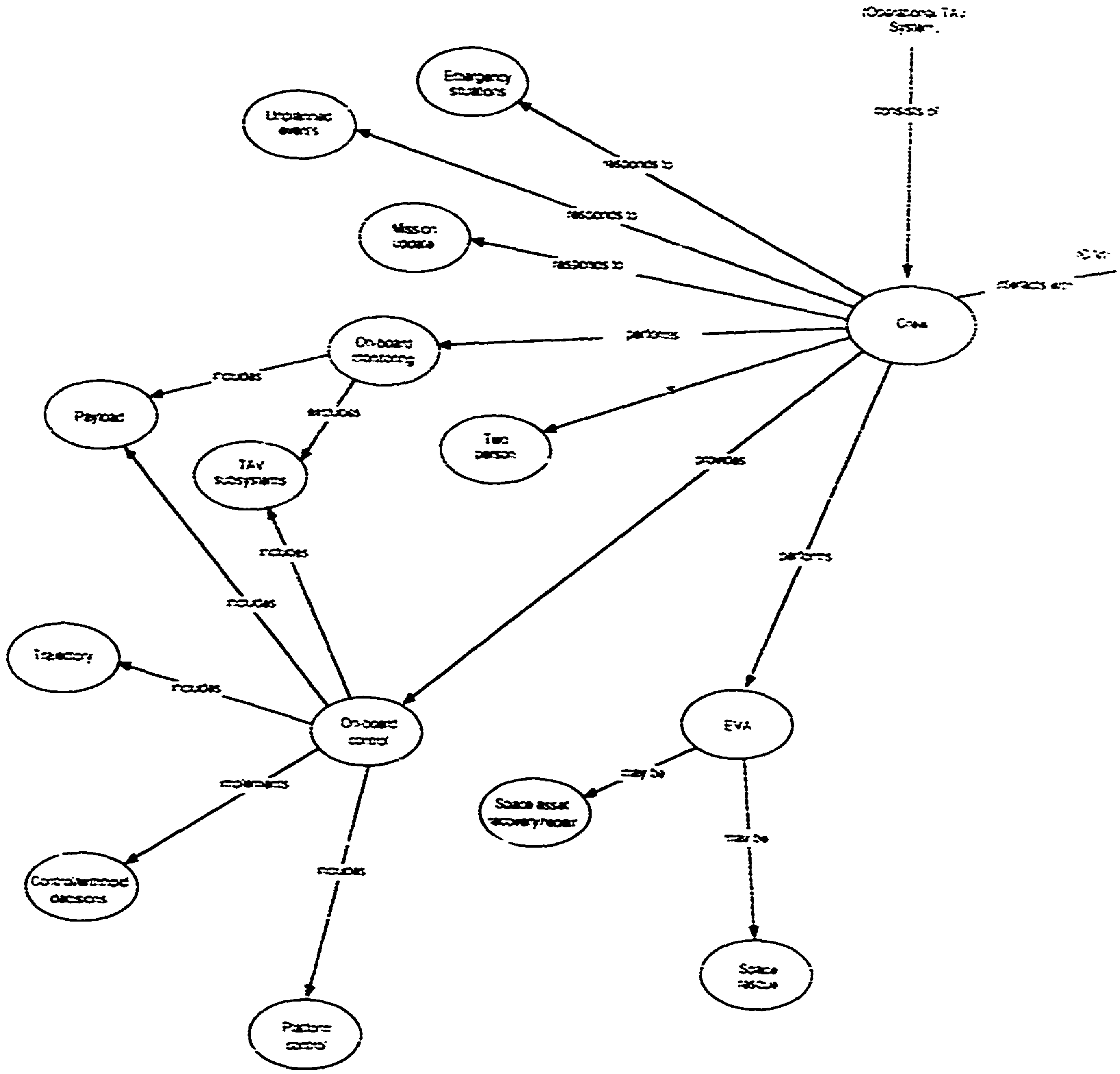

Figure 12a. Concept Map of Crew and C/UI Subsystems

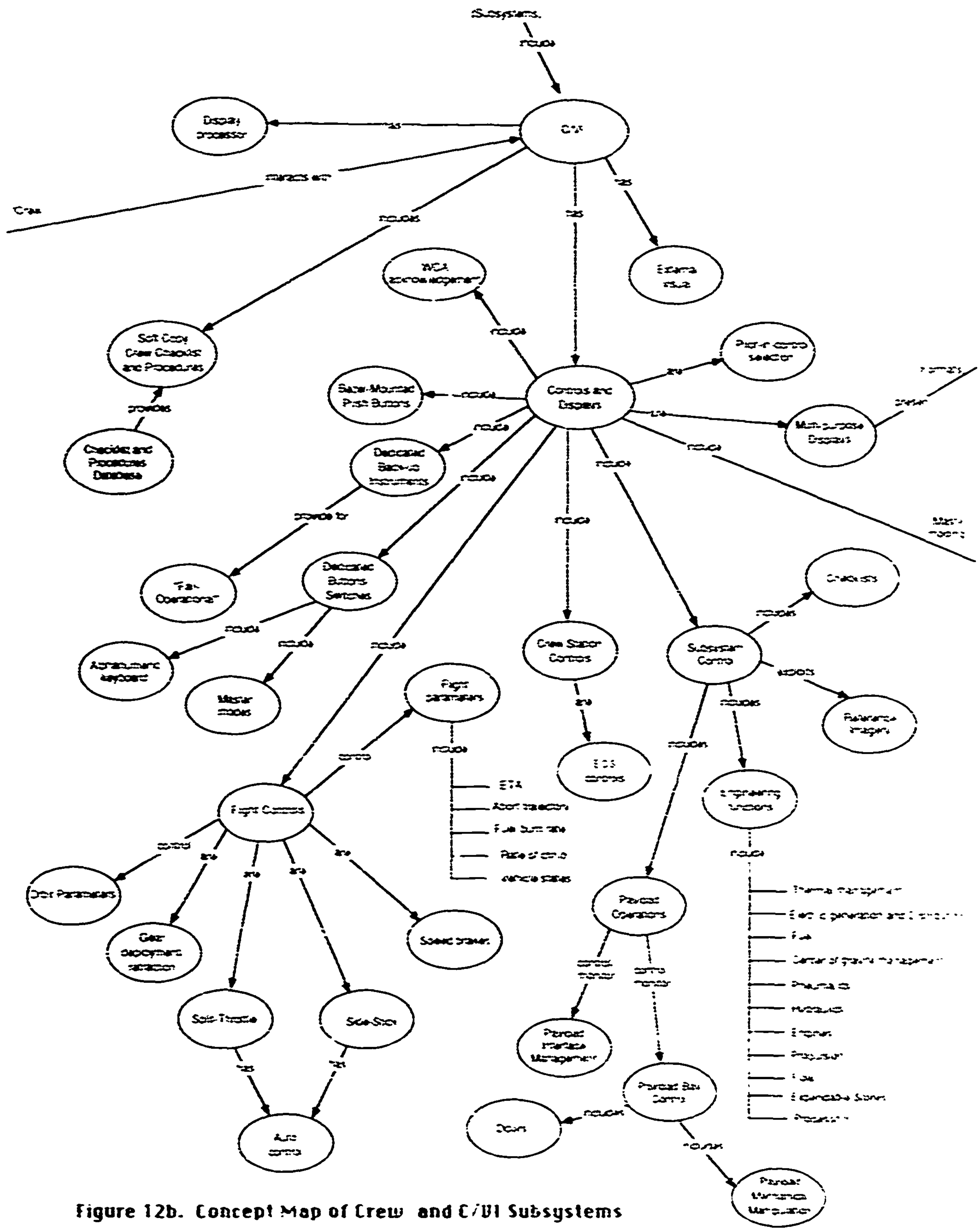

Figure 12b. Concept Map of Crew and C/UI Subsystems

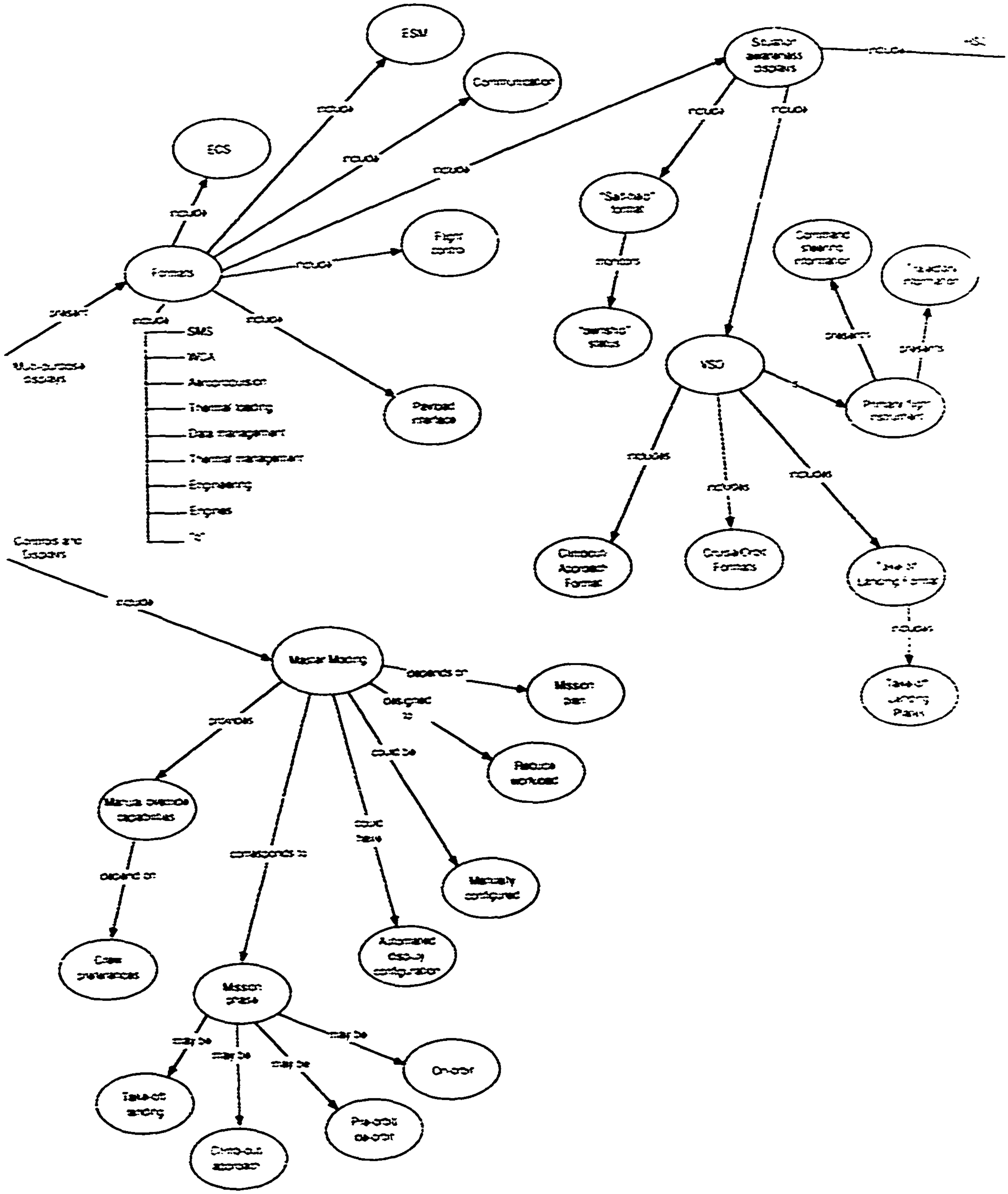

Figure 12c. Concept Map of Crew and C/UI Subsystems

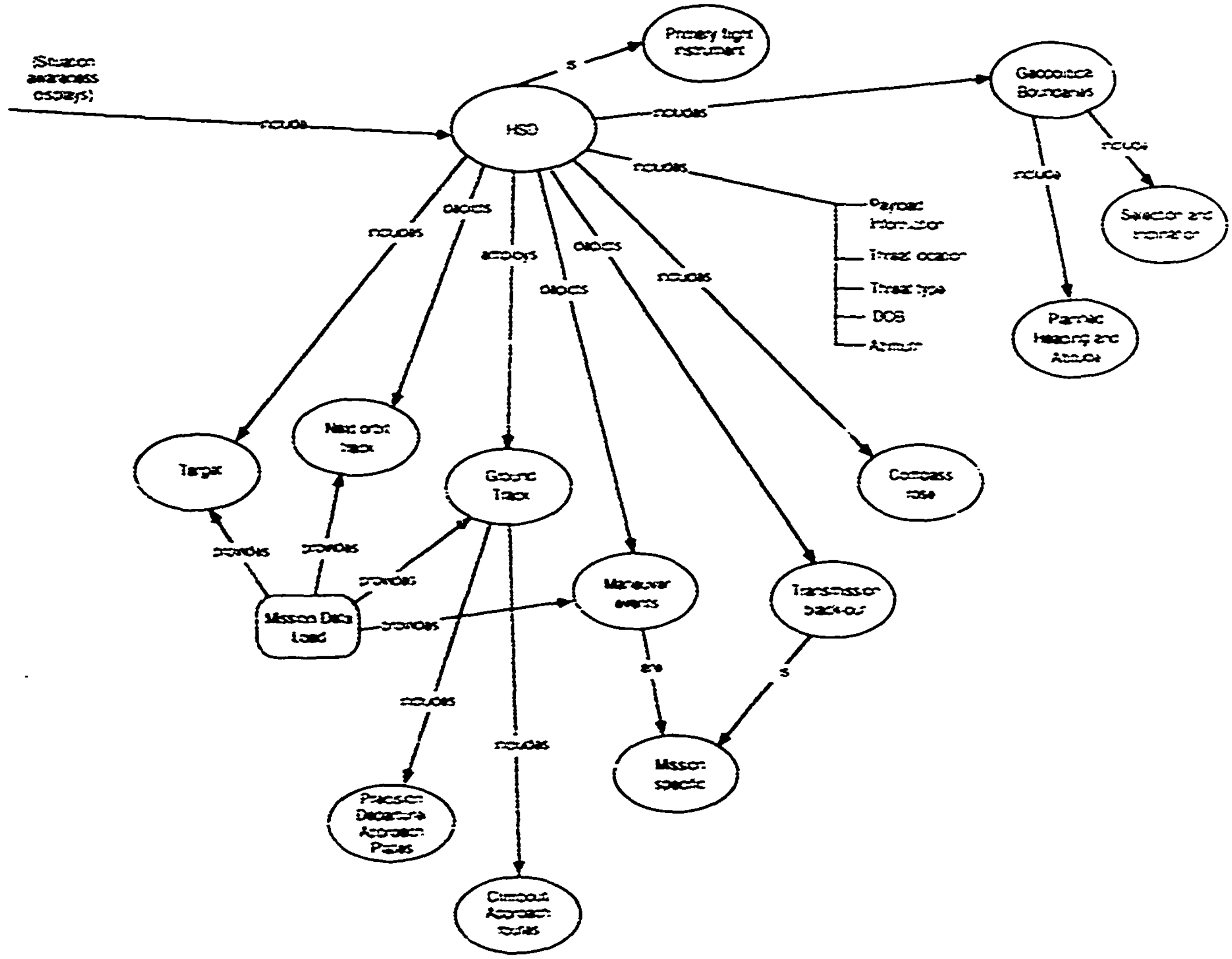

Figure 12d. Concept Map of Crew and C/VI Subsystems

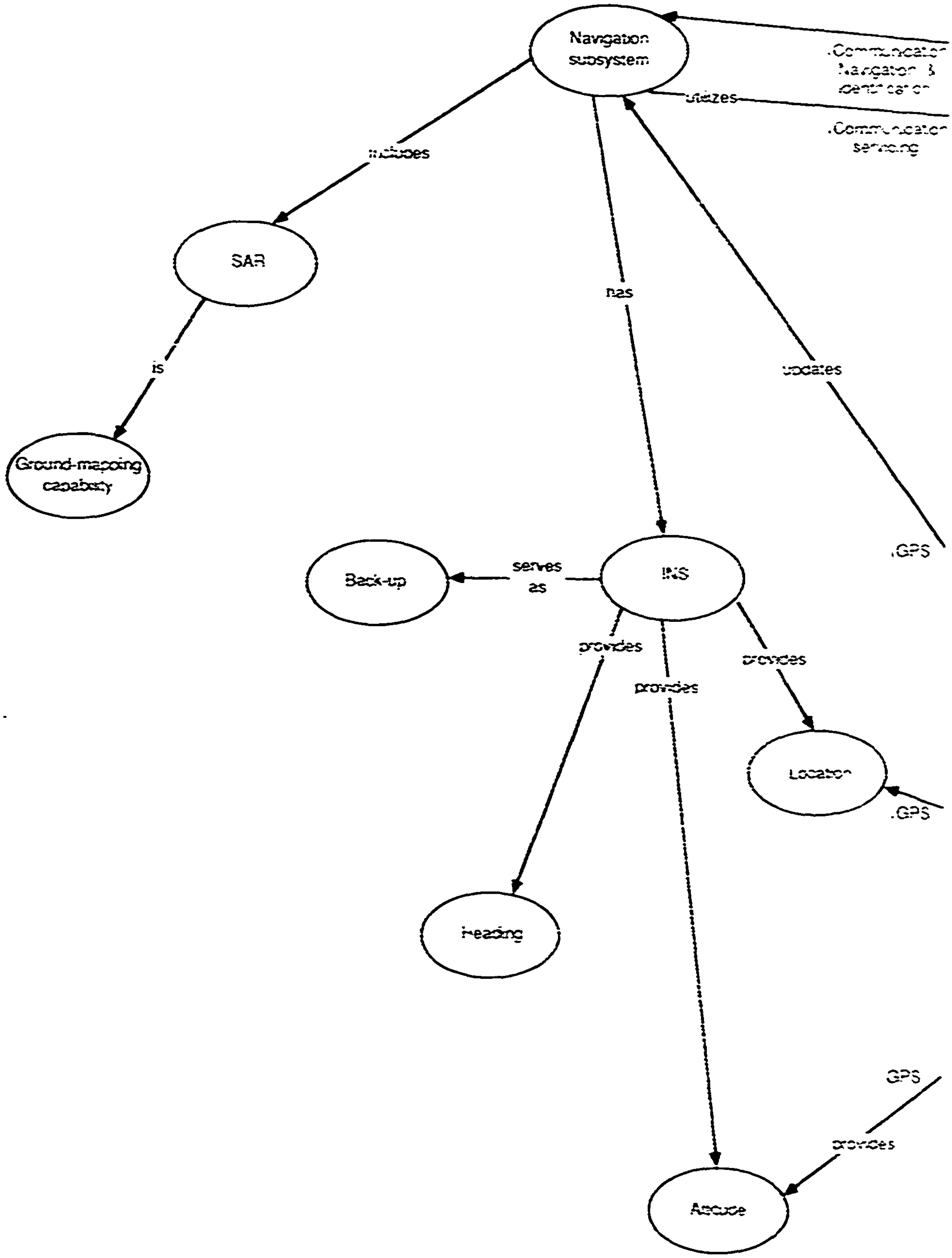

Figure 13a. Concept Map of Communication, Navigation, and Identification Subsystem

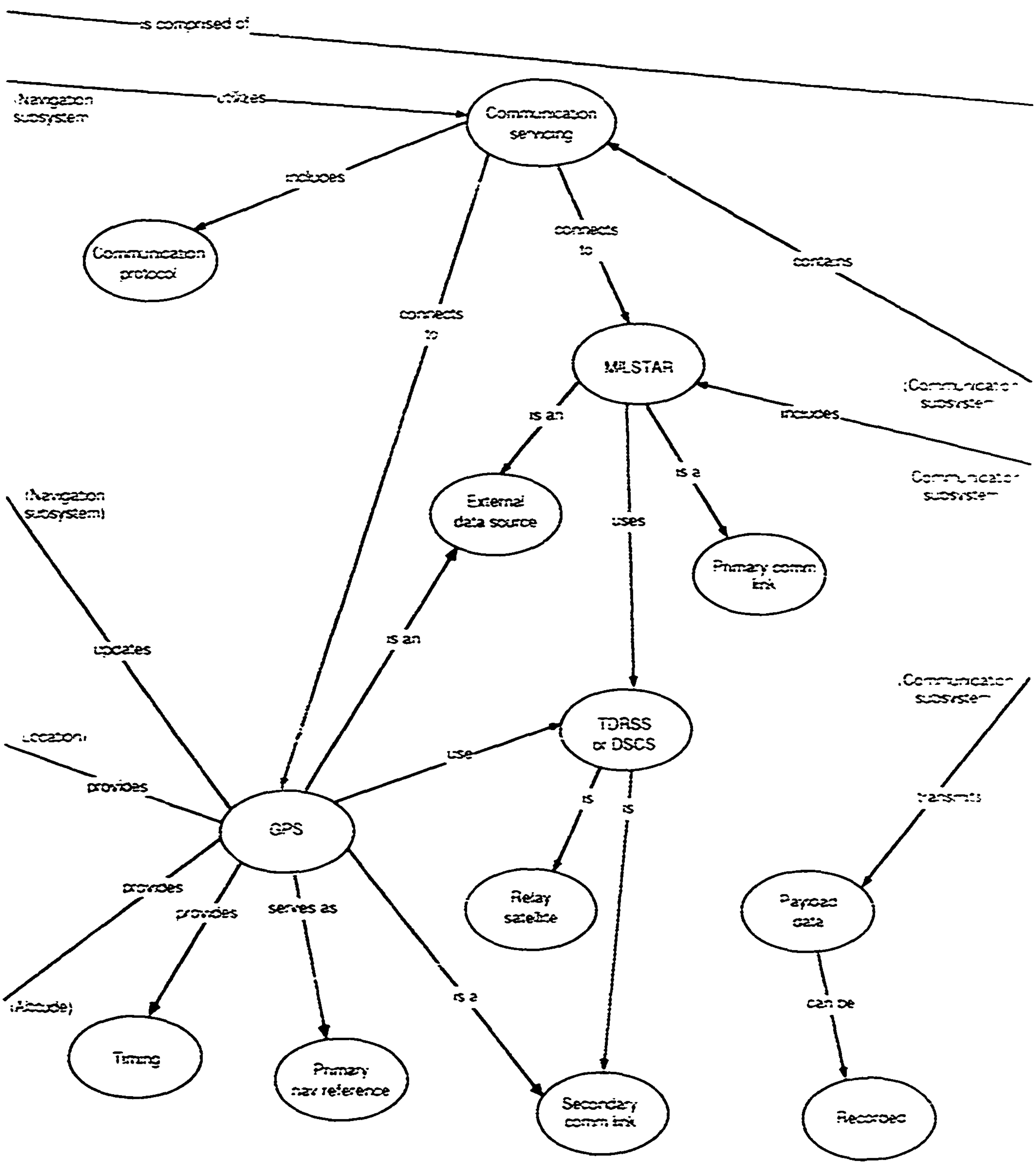

Figure 13b. Concept Map of Communication, Navigation, and Identification Subsystem

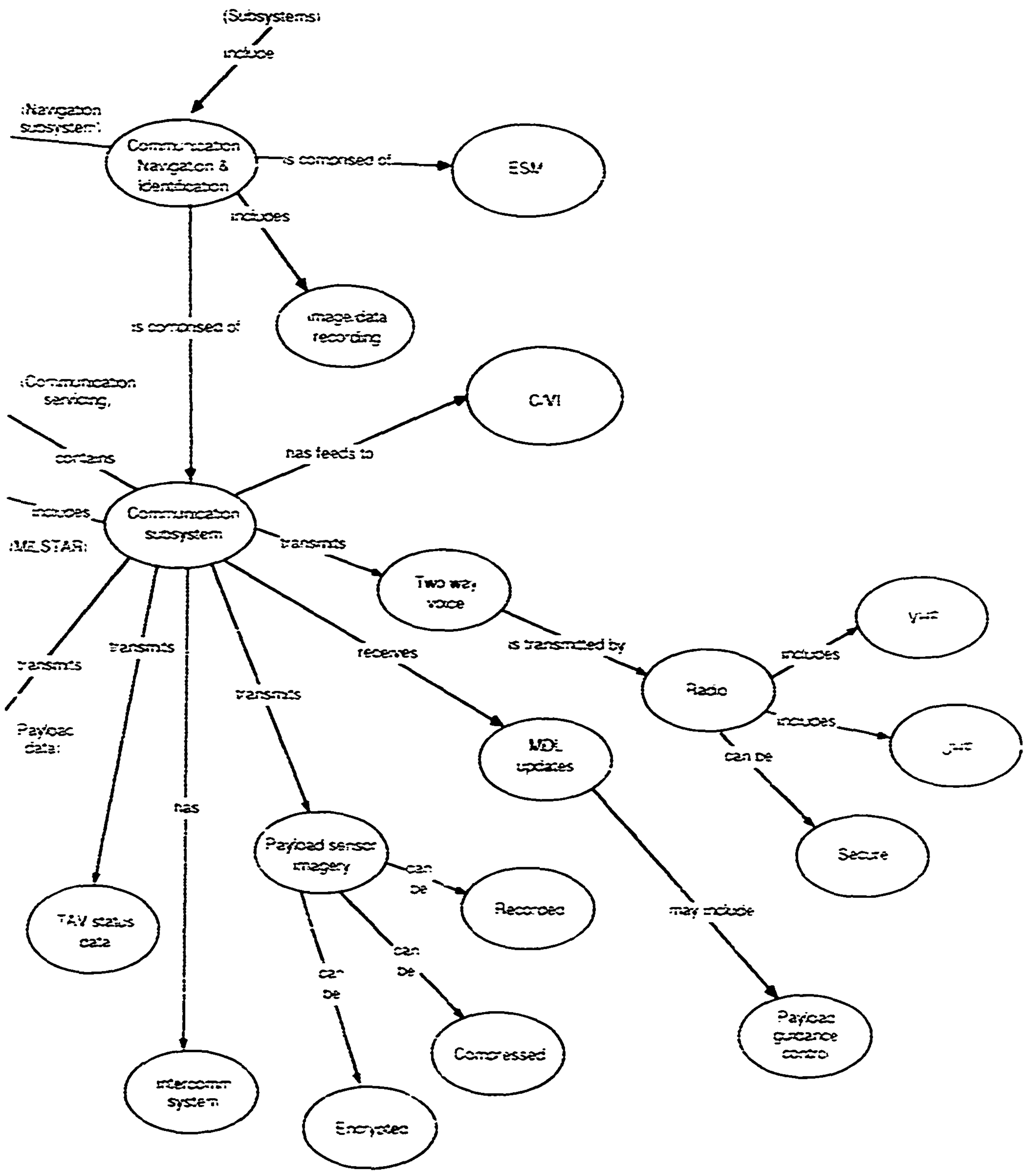

Figure 13c. Concept Map of Communication, Navigation, and Identification Subsystem

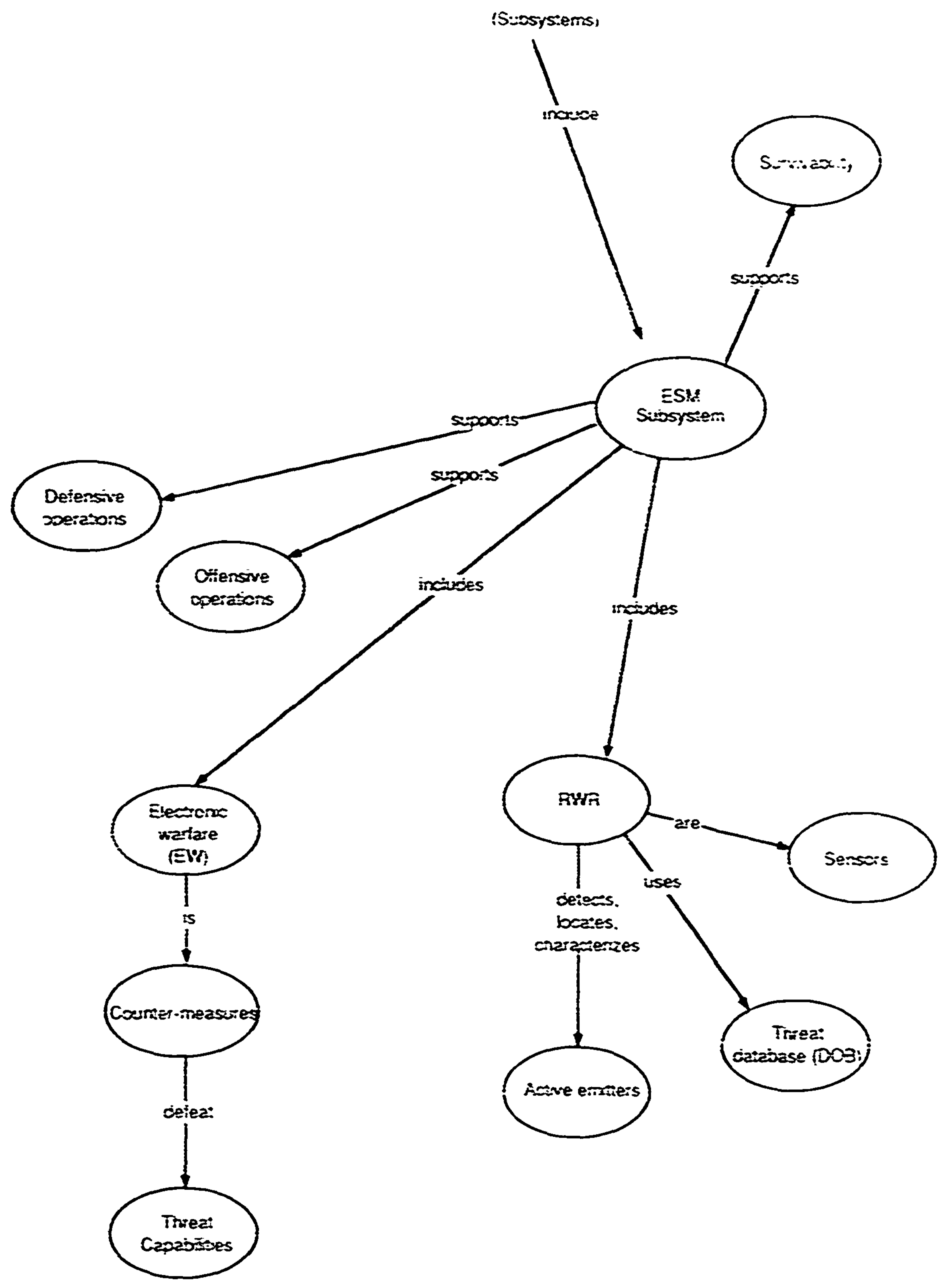

Figure 14. Concept Map of Electronic Support Measures Subsystem

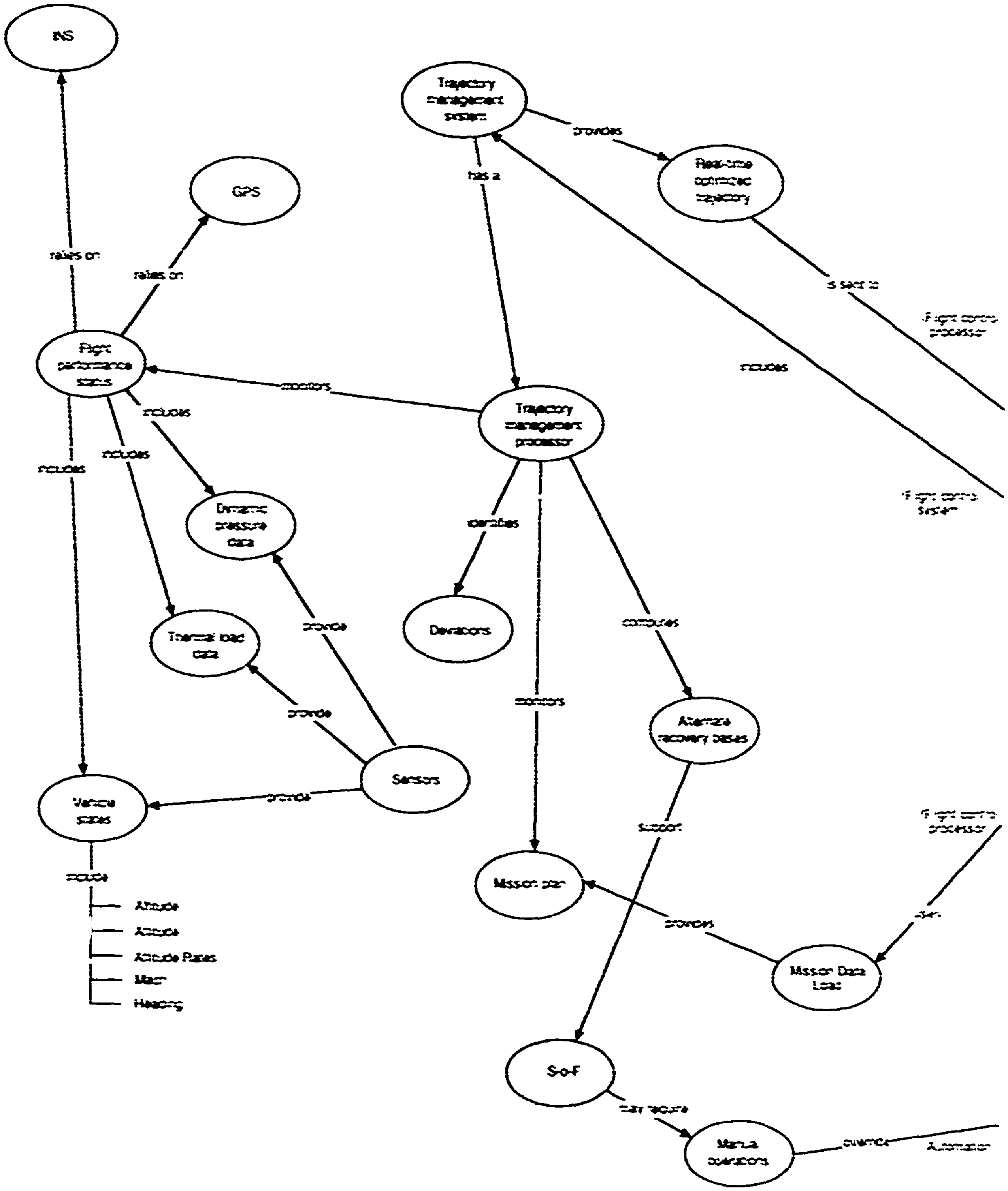

Figure 15a. Concept Map of Flight Control Subsystem

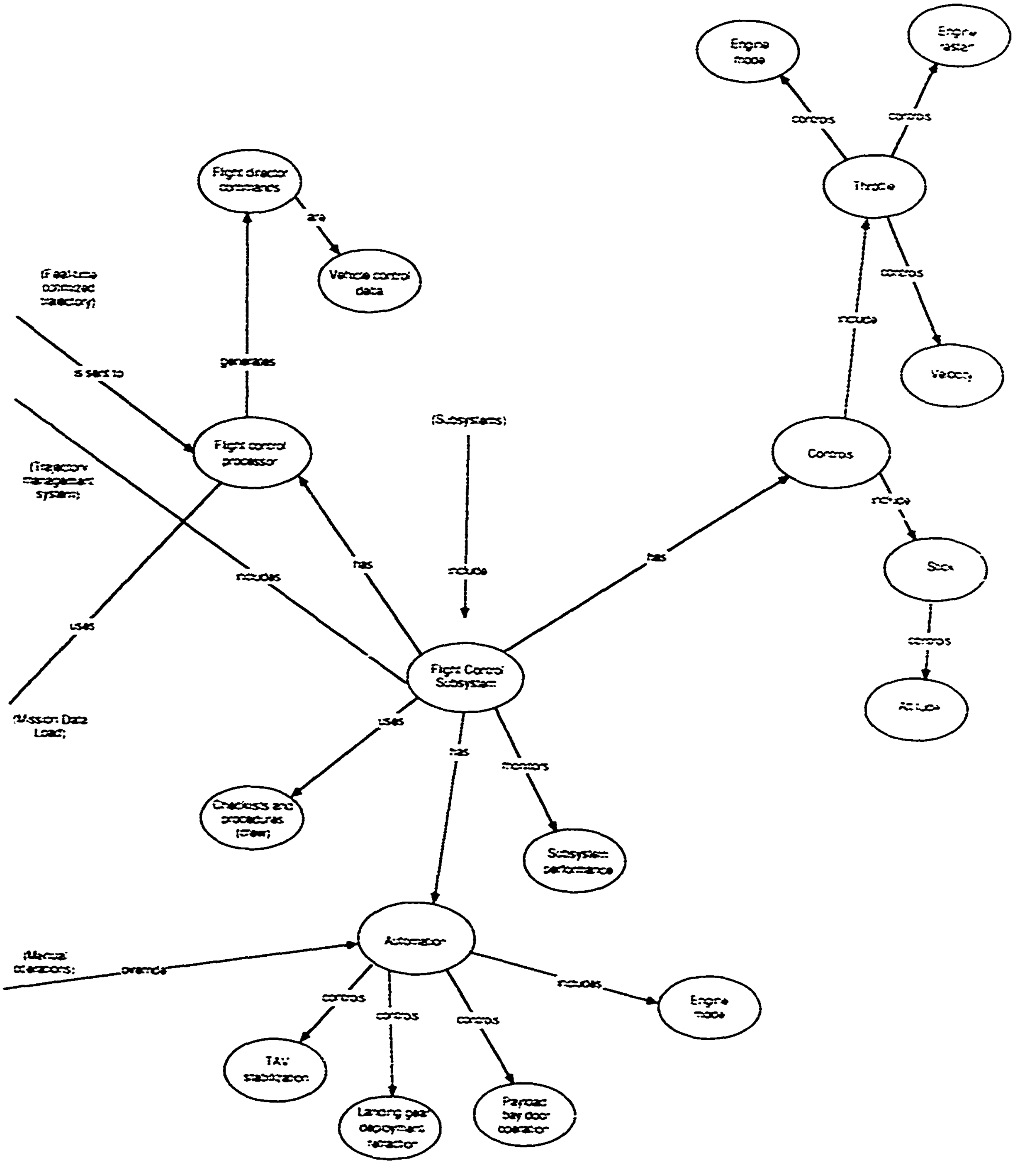

Figure 15b. Concept Map of Flight Control Subsystem

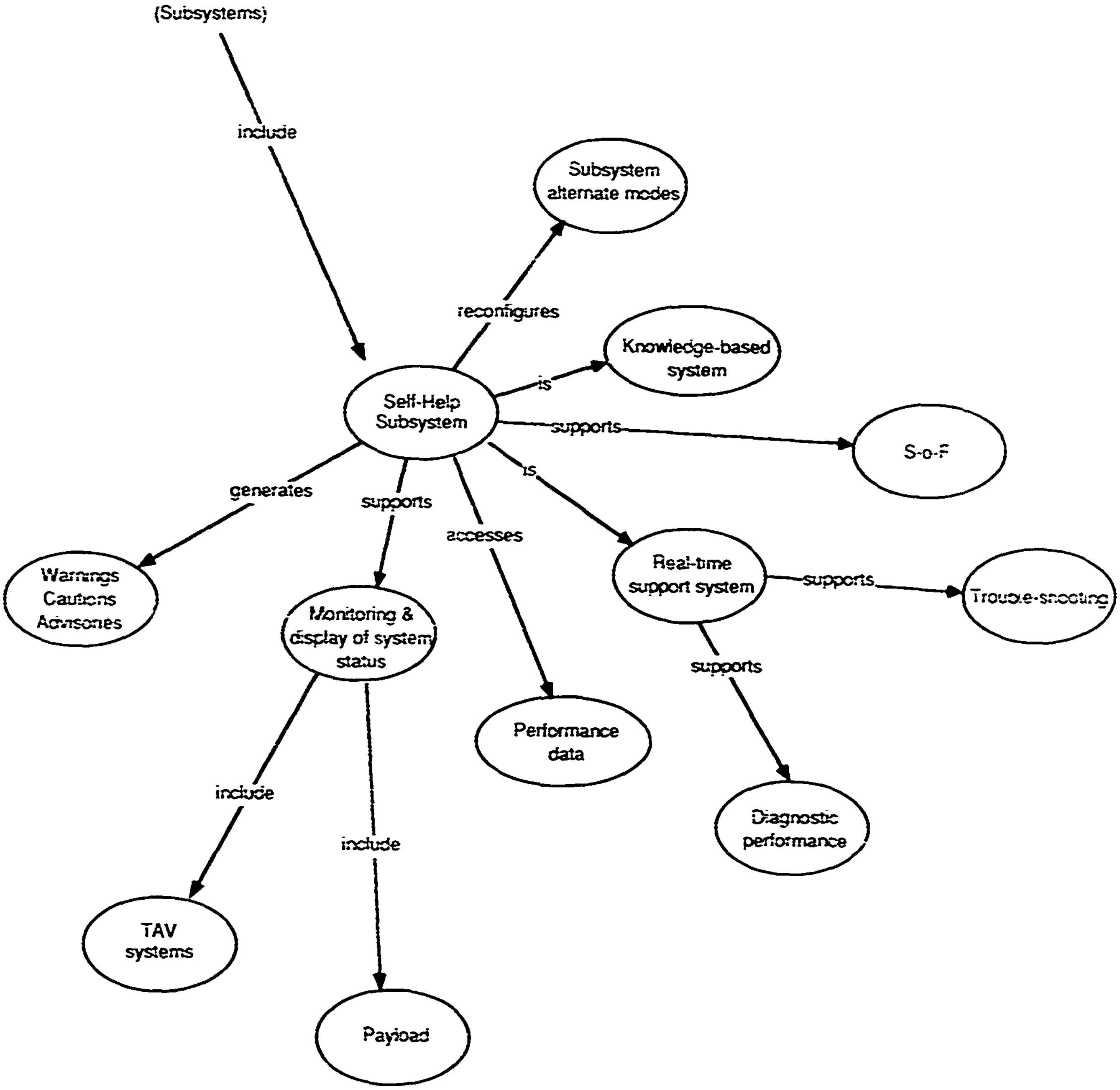

Figure 16. Concept Map of "Self-Help" Subsystem

Figure 17 presents the Environmental Control Subsystem. Figure 18 is the map of the Stores and Thermal Management Subsystems. Figure 19 is the concept map of the TAV's propulsion system.

The TAV's Data Management Subsystem is mapped in Figure 20 (a through c). The map also includes the MDL and the on-board data bases.

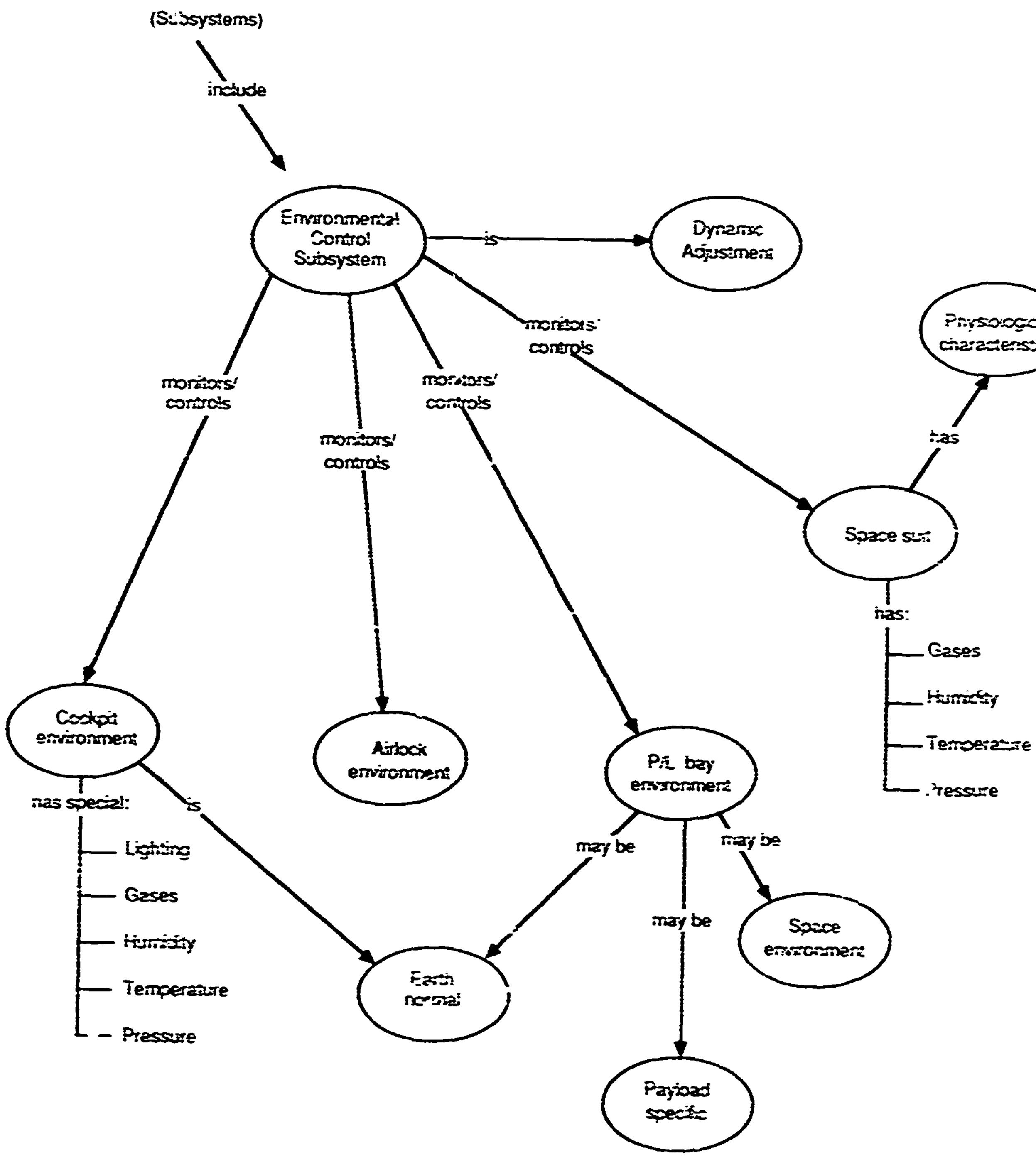

Figure 17. Concept Map of Environmental Control Subsystem

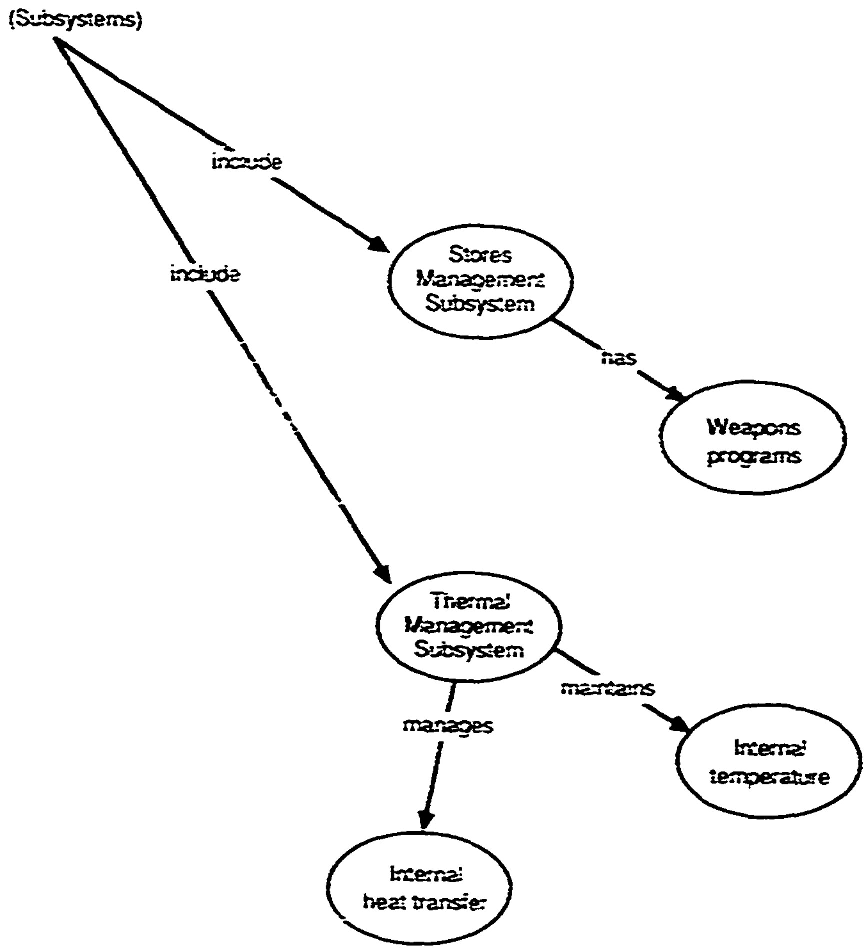

Figure 18. Concept Map of Stores Management and Thermal Management Subsystems

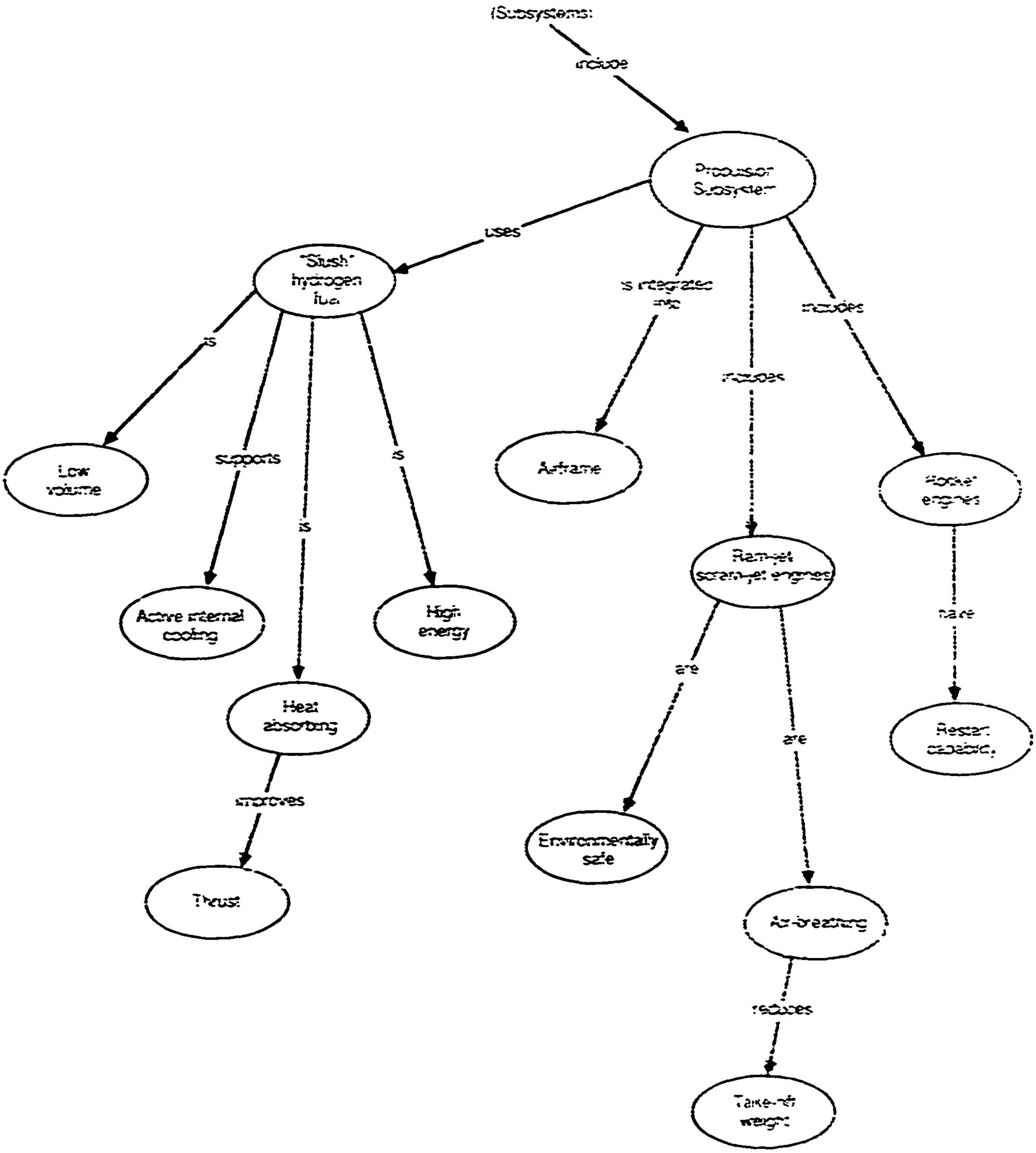

Figure 19. Concept Map of Propulsion Subsystem

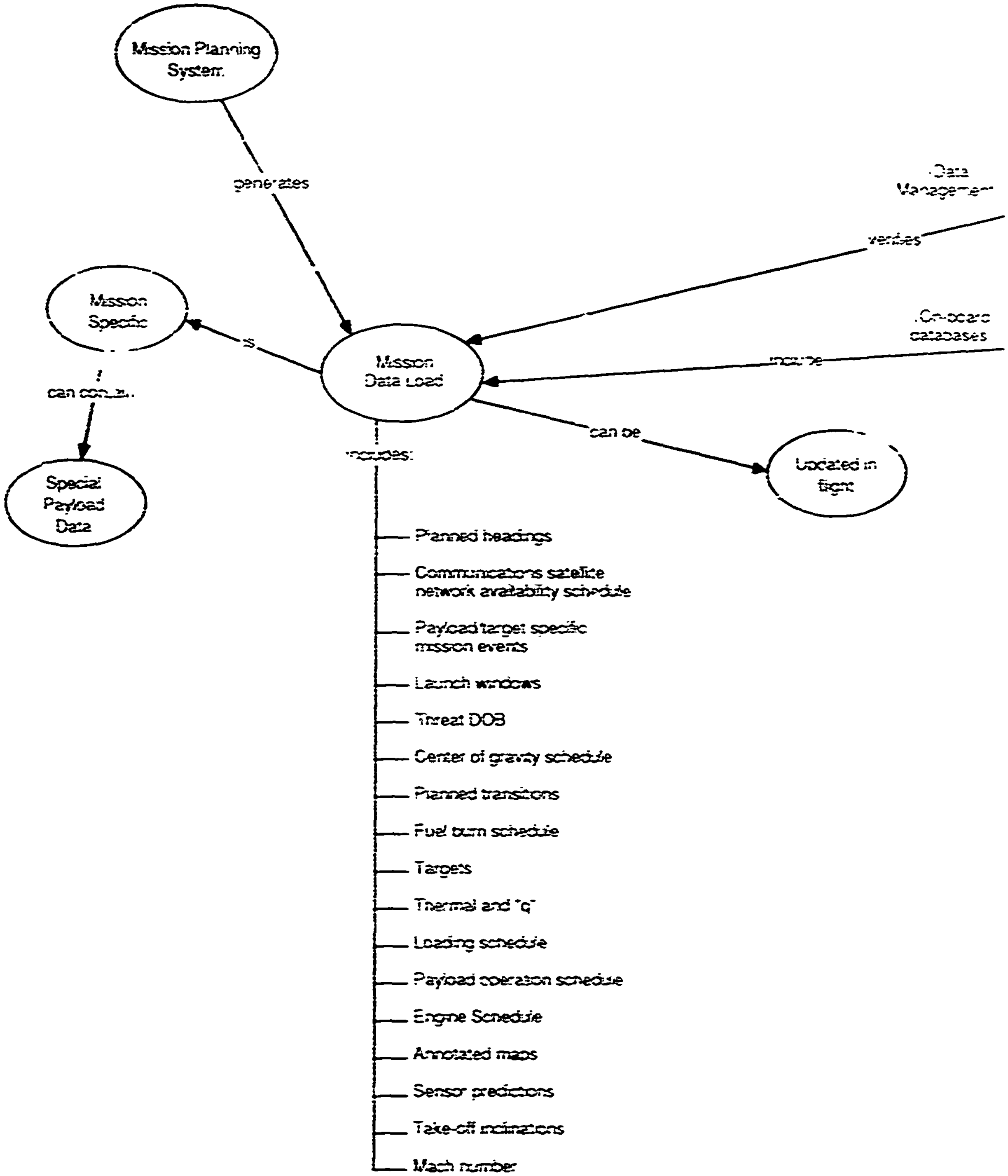

Figure 20a. Concept Map of Data Management Subsystem

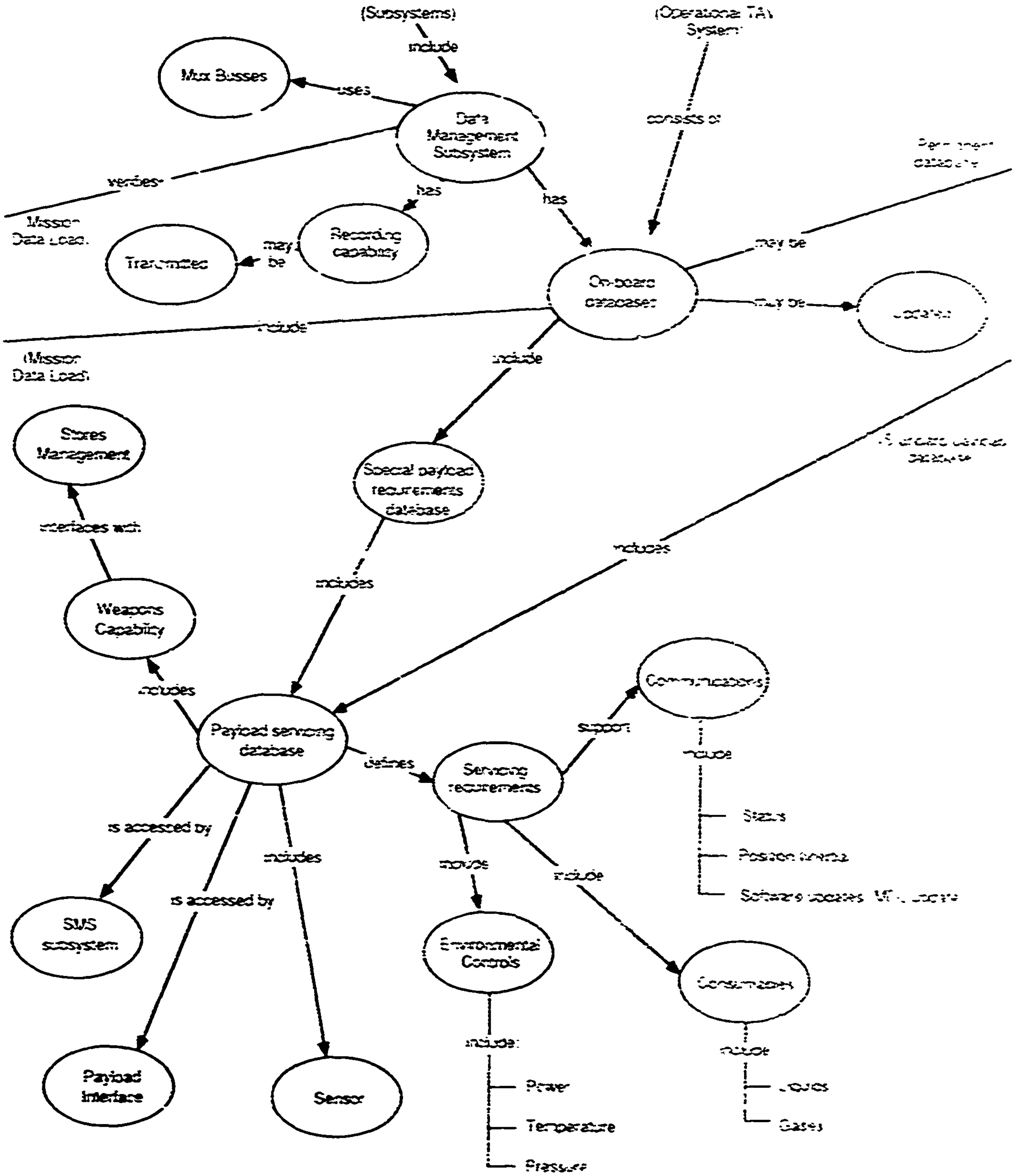

Figure 20b. Concept Map of Data Management Subsystem

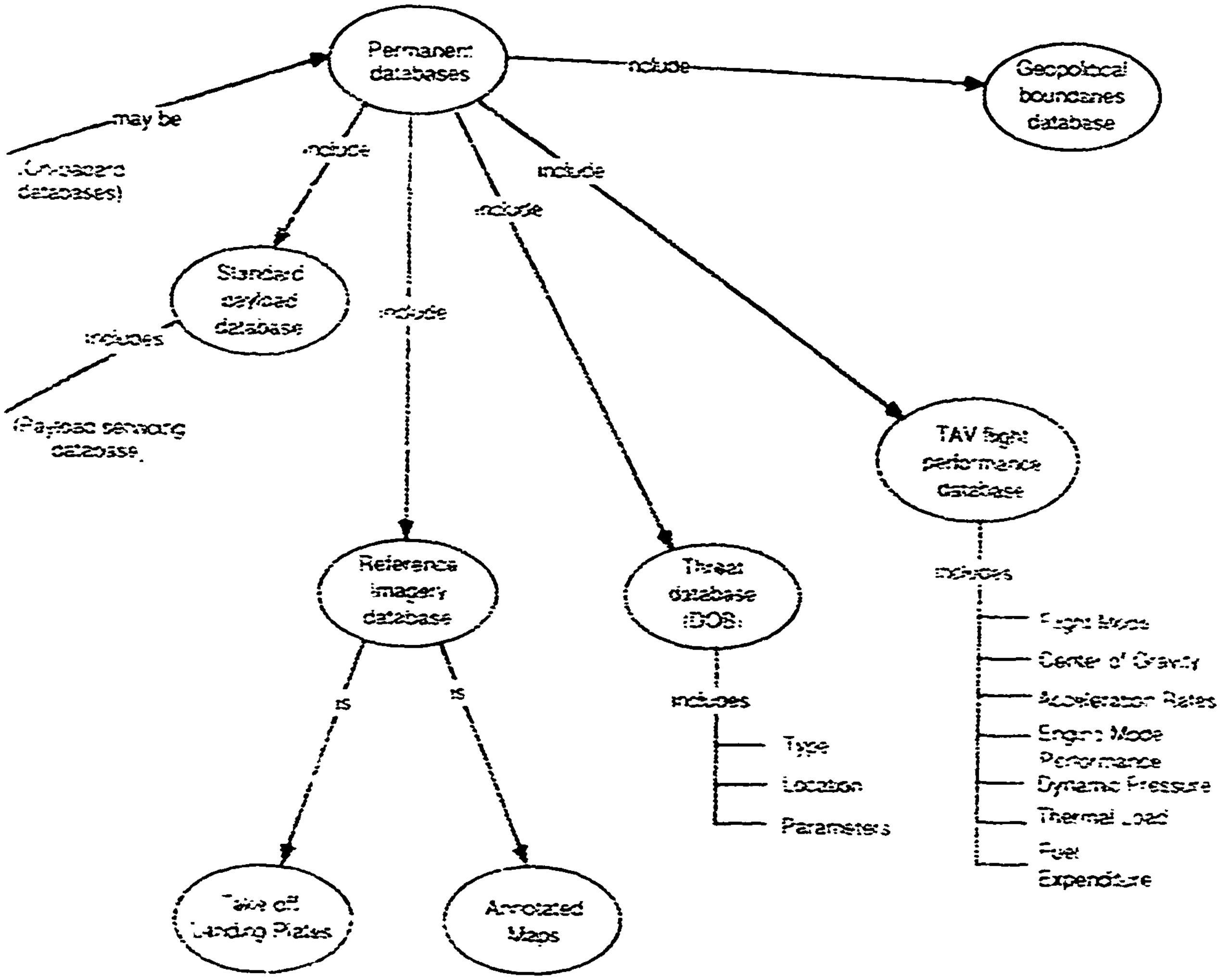

Figure 20c. Concept Map of Data Management Subsystem

SECTION III

MISSION EVENT SEQUENCE

The context for performing the Information Requirements Analysis Task is provided by the Mission Event Sequence (MES). The MES is a time-ordered sequence for TAV system functions. The time ordering is preceeded by the successive phases of the TAV operational mission. The MES is depicted in a series of function/flow diagrams. This series is divided into two groupings: those system functions which are performed prior to Takeoff and those which take place Post-Takeoff. The top level MES flow diagrams (Figures 21 and 22) reflect this division. Each of the blocks in the top level flow diagram is decomposed into more detailed function/flow diagrams which correspond to a major preparatory activity or mission phase. Each of the blocks in the detailed function/flow diagrams represents a specific TAV system function. In general, the crew must accomplish a specific standard operating procedure in order to exercise the TAV system function. (These procedures are developed in the IDEF0 depictions presented and discussed in Section IV of the report.)

The MES begins with the receipt of the mission Tasking Order by the operations control center at the TAV main operating base (MOB). The Tasking Order contains all the information required for the construction of the Mission Plan:

- P/L(s) to be employed/deployed
- time(s) on target(s)

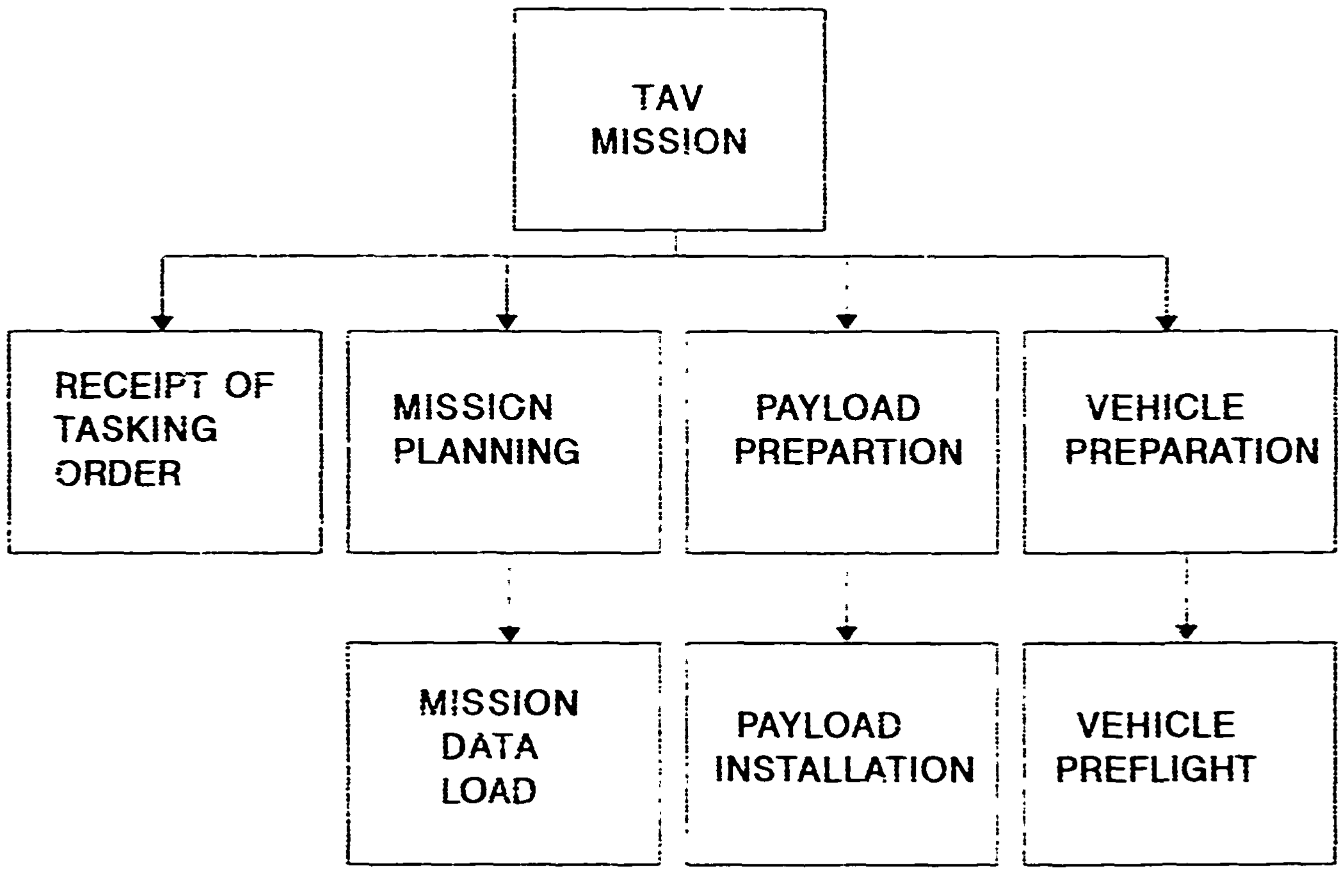

Figure 21. Mission Event Sequence: Flow Diagram 1

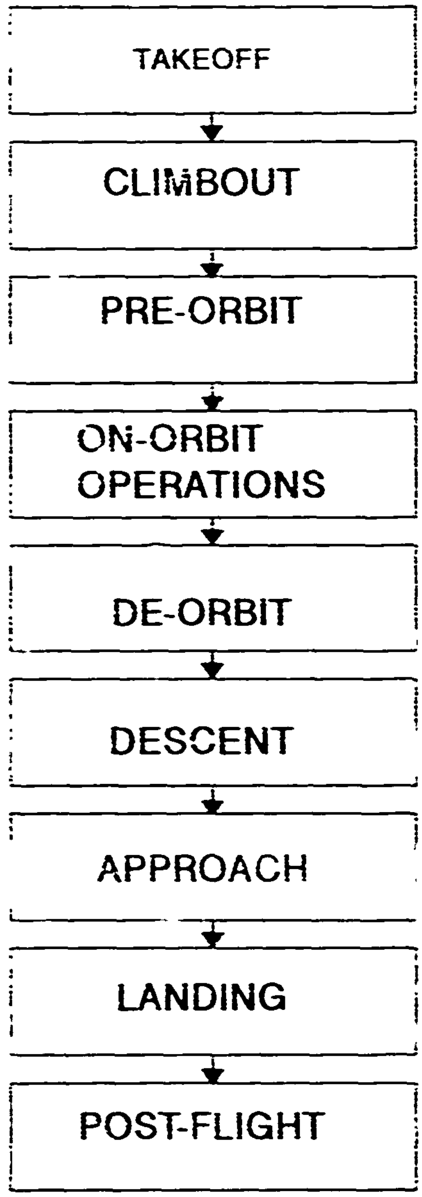

Figure 22. Mission Event Sequence: Flow Diagram 2

- mission criteria to be achieved
- rules of engagement
- special factors (e. g., orbital parameters for space asset rendevous)

These mission requirements are used to generate Takeoff time and orbital inclination data. They are supplemented with intelligence data provided by the TAV Unit's Combat Intelligence Shop regarding targets and any relevant threat situation. Additional mission planning data are provided by the Unit's Meteorology Officer. All these inputs, together with existing TAV performance and P/L capability data bases, are exploited by the TAV Mission Planning System in developing the Mission Data Load (MDL).

In general, the TAV fleet is tasked with supporting pre-planned missions such as space asset resupply or satellite servicing. The MES remains as described except that the Tasking Order may have been received weeks to months in advance.

P/L Preparation (Figure 23) is a precursor activity. P/Ls, which support a variety of standard or special mission requirements, are received at the TAV MOB independent of specific tasking. The P/L is inspected and tested at the MOB's P/L Processing Facility and installed into a standardized TAV P/L container. The containerized P/L is maintained in a pre-mission state until required for employment.

The receipt of the Tasking Order triggers the Vehicle Preparation stage of pre-mission activities (Figure 24). Each

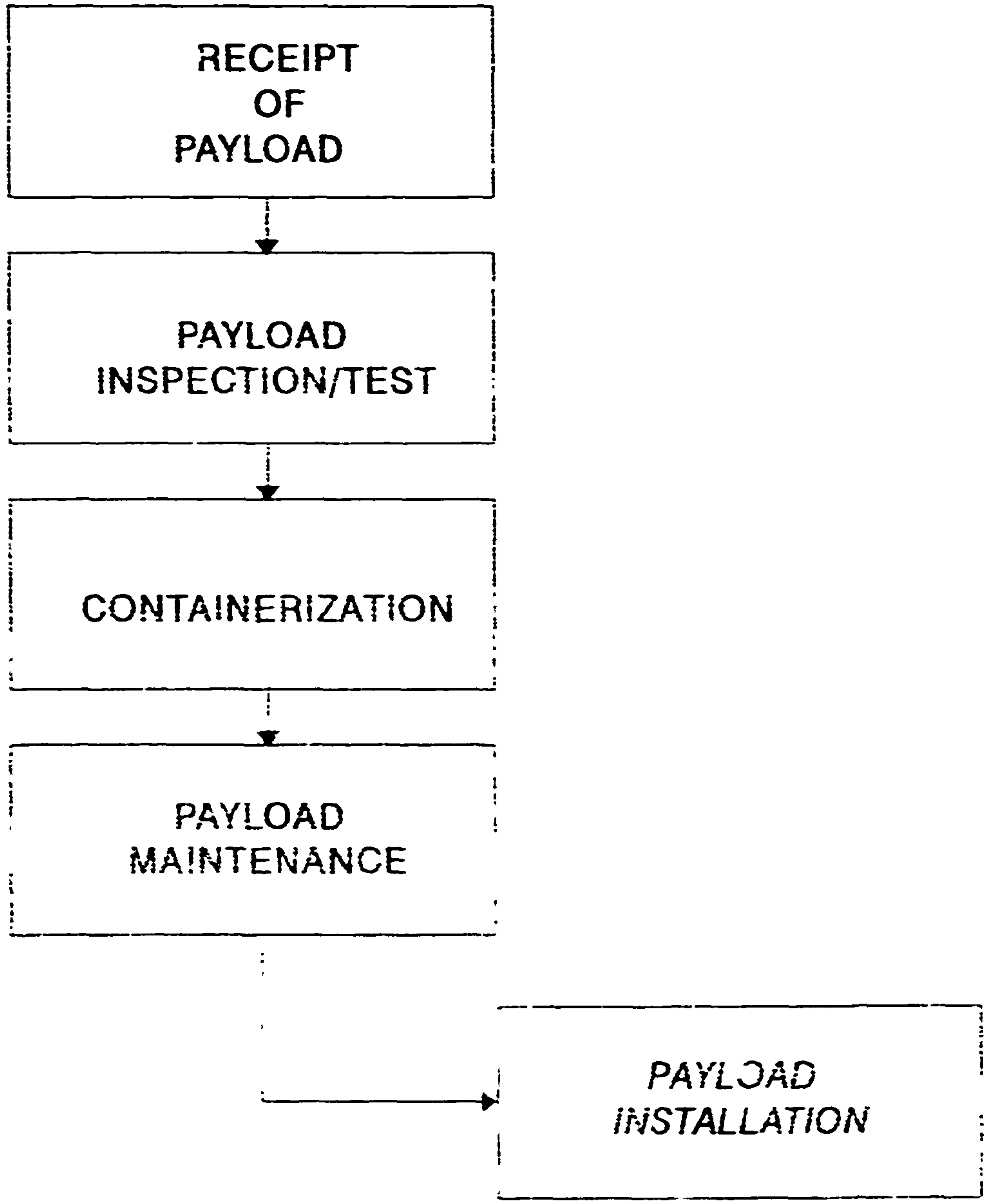

Figure 23. Payload Preparation

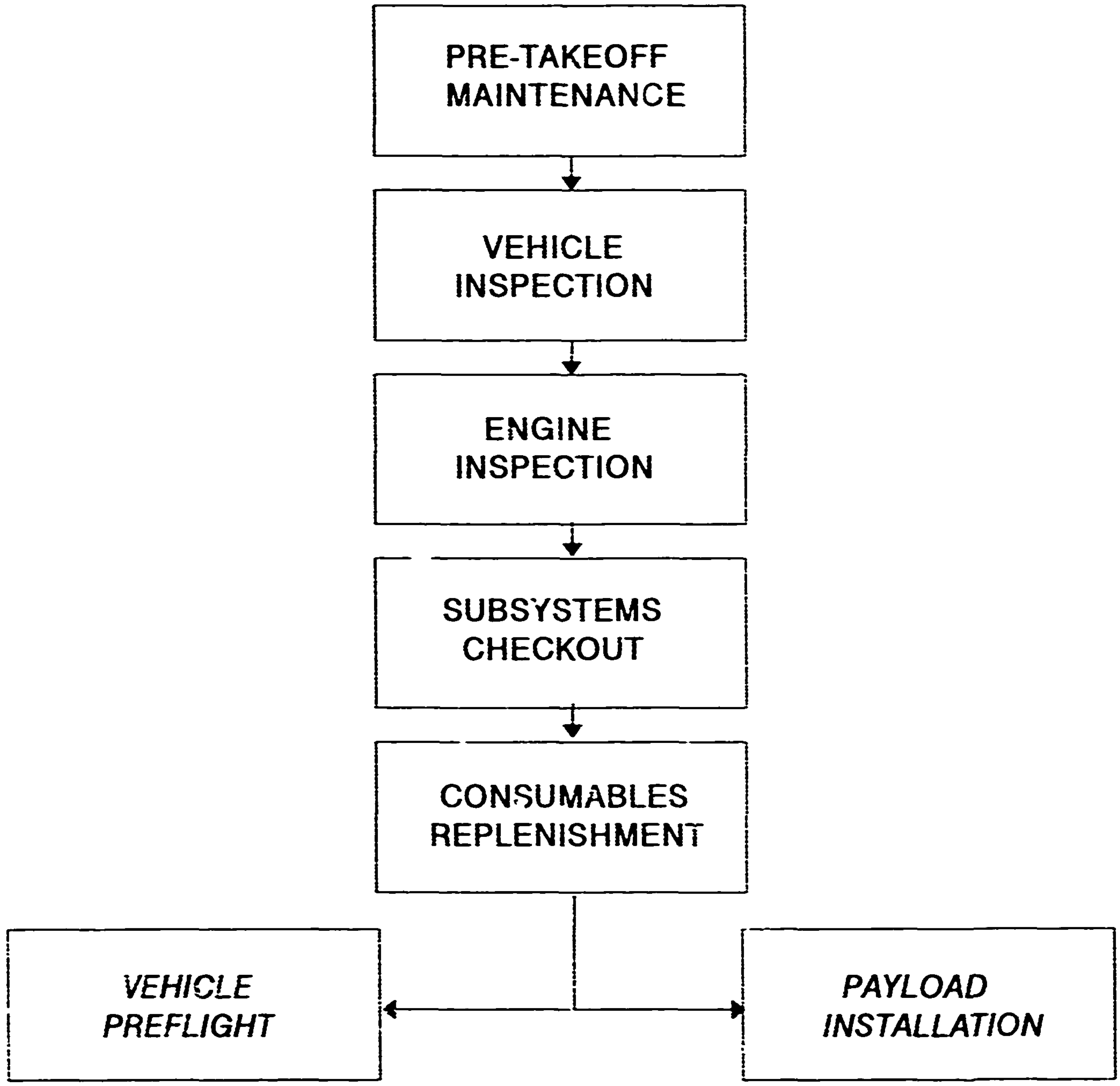

Figure 24. Vehicle Preparation

TAV has been maintained in a pre-mission readiness state. Once a specific "tail number" has been identified for the new mission, pre-flight maintenance is performed by the ground crew to bring the vehicle up to a mission-ready state. The vehicle and engines are inspected and on-board consumables, required for either the crew or P/L during the mission, are replenished.

The P/L Installation stage of the pre-mission activities (Figure 25) results in the joining of the mission P/L(s) to the TAV. The vehicle is towed to the P/L Preparation Facility. A P/L "wakeup" procedure is performed to bring the P/L to a state of mission readiness. The P/L is physically inserted into the TAV's P/L bay and interconnections are made with the TAV's P/L Interface Subsystem through the P/L Interface. The P/L is again tested and verified as "mission ready." From this point on, P/L servicing requirements are satisfied by the TAV, with no external assistance.

Vehicle Preflight (Figure 26) constitutes the final, pre-Takeoff stage of the MES. The vehicle is fueled with slush hydrogen and the organic INS is ground aligned. The ground crew configures the C/VI and tailors the MPD formats preparatory to loading the MDL into the TAV's data bases. The MDL is physically loaded into the TAV and verified by the ground crew. P/L servicing continues to be provided by the TAV.

At approximately the same time as these activities are taking place, the TAV's crew has performed a mission briefing and has employed the Mission Rehearsal Device (MRD, part of the TAV

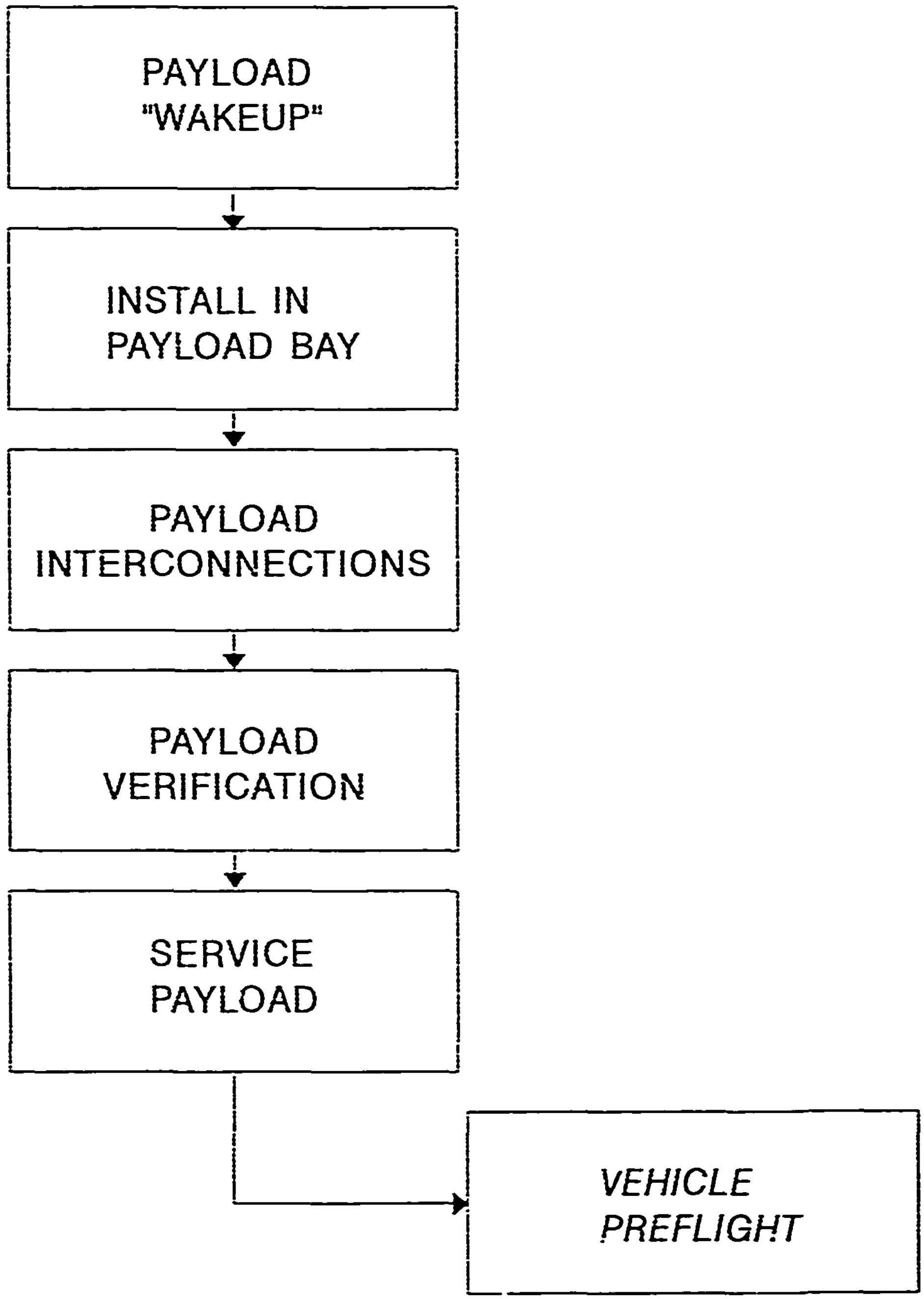

Figure 25. Payload Installation

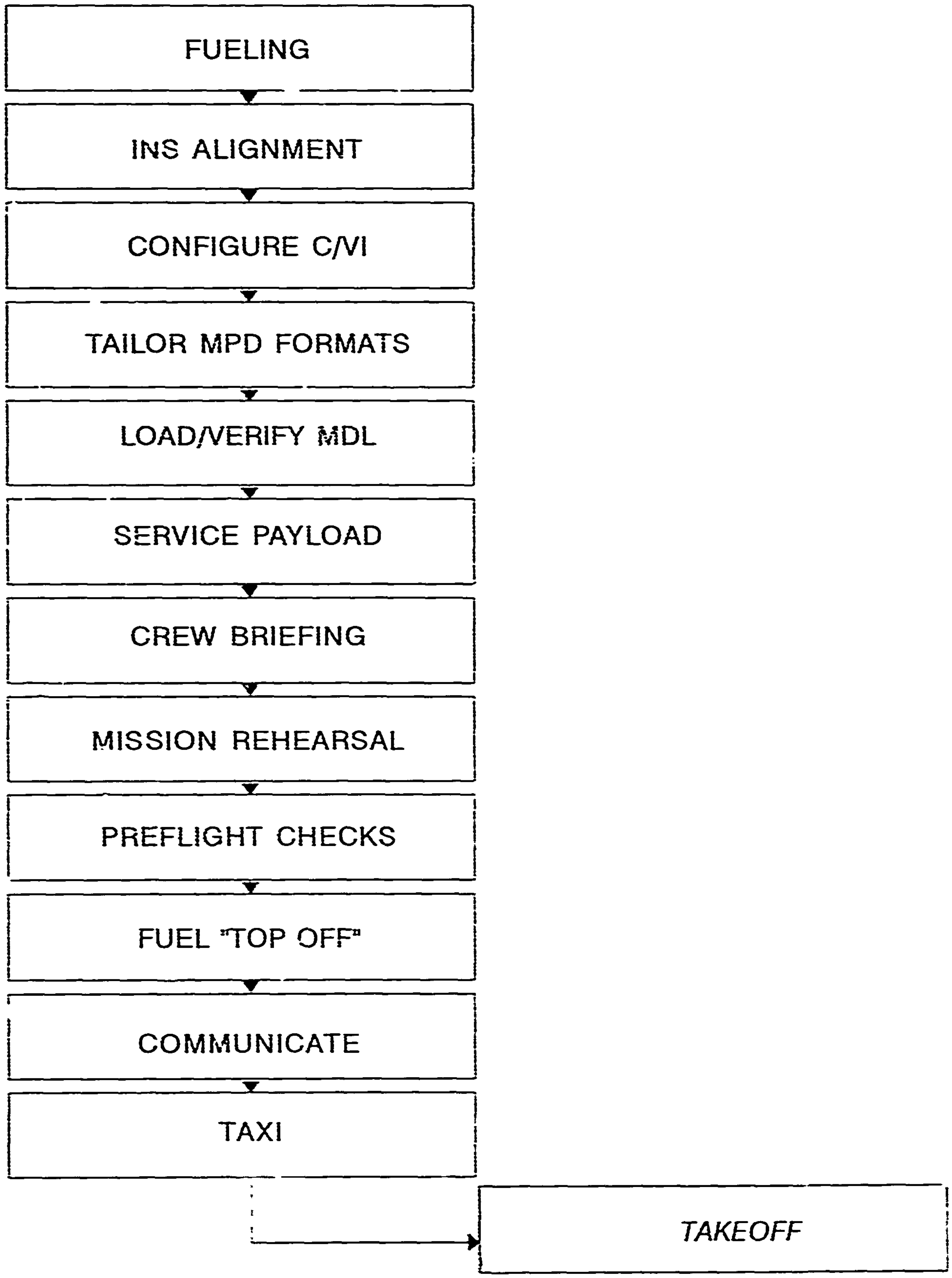

Figure 26. Vehicle Preflight

training support system) to "dry run" the entire mission. The mission rehearsal reinforces the crew briefing and emphasizes mission pacing and prebriefed tactics. The MRD uses the MDL to provide the Mission Plan for the mission rehearsal scenario.

The TAV aircrew enters the vehicle and performs preflight checks. These include both interior and exterior inspections, subsystem testing, and P/L checkout. The fuel load is brought to full capacity. The crew communicates mission readiness to the Operations Center and, upon receiving approval, taxis the vehicle to the end of the assigned runway.

The crew configures the vehicle for Takeoff (Figure 27). They also configure the C/VI and tailor the selection and arrangement of MPD formats to support this mission phase. They monitor the ramjet (mode) engines, service the P/L, and monitor TAV subsystems. When system readiness has been confirmed, they execute an aircraft-like Takeoff. Once airborne, the landing gear is retracted and the crew communicates the successful takeoff to the tower.

The next phase of the mission is Climbout (Figure 28). The crew (re)configures the control surfaces, as required. They configure the C/VI and tailor the MPD formats to support their information requirements. Automated servicing of the P/L is continued by the P/L Interface Subsystem. The crew continues to monitor the TAV subsystems. The TAV continues to climb along the selected mission inclination, executing a constant dynamic pressure climbout. The crew monitors the vehicle's trajectory.

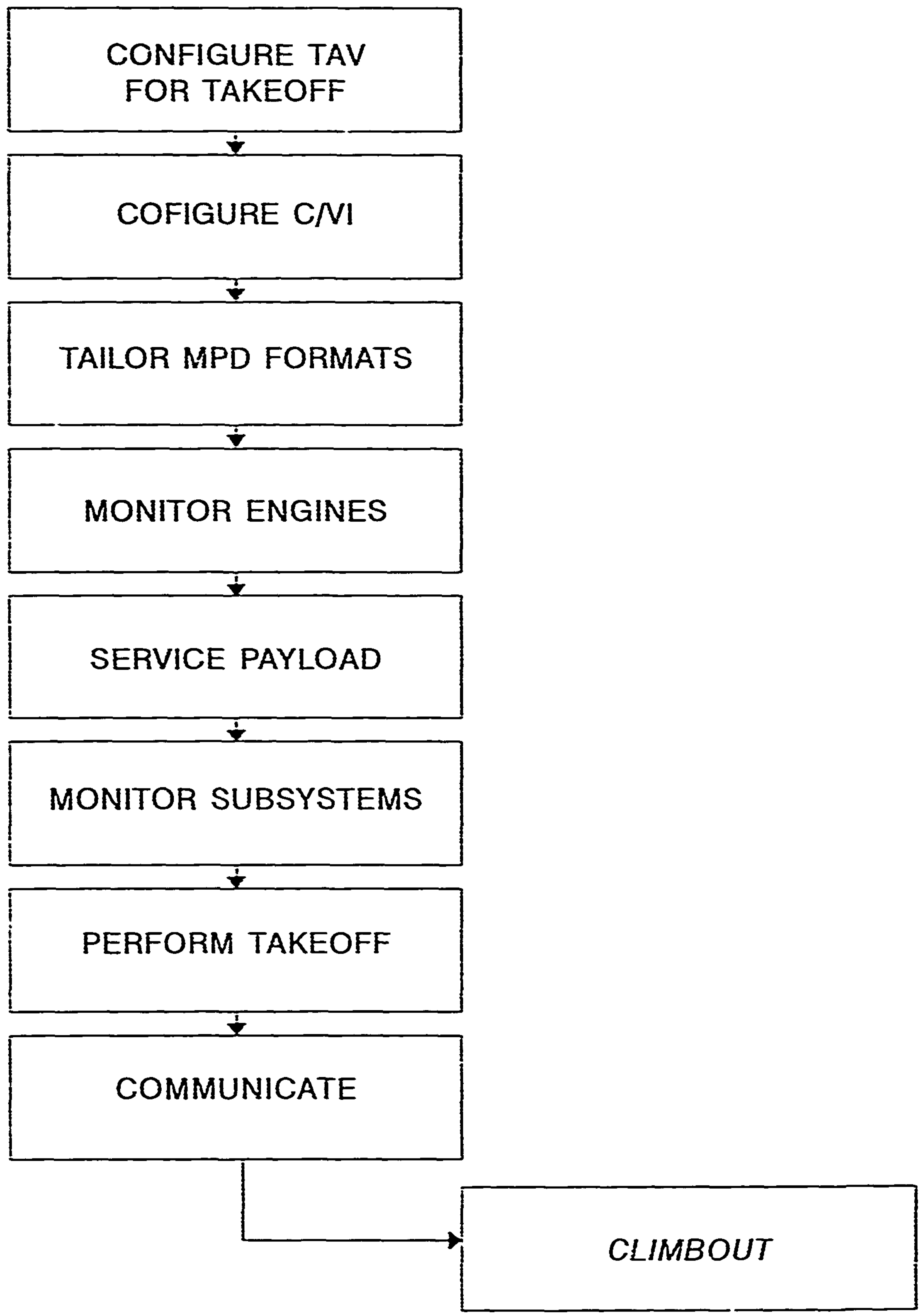

Figure 27. Takeoff

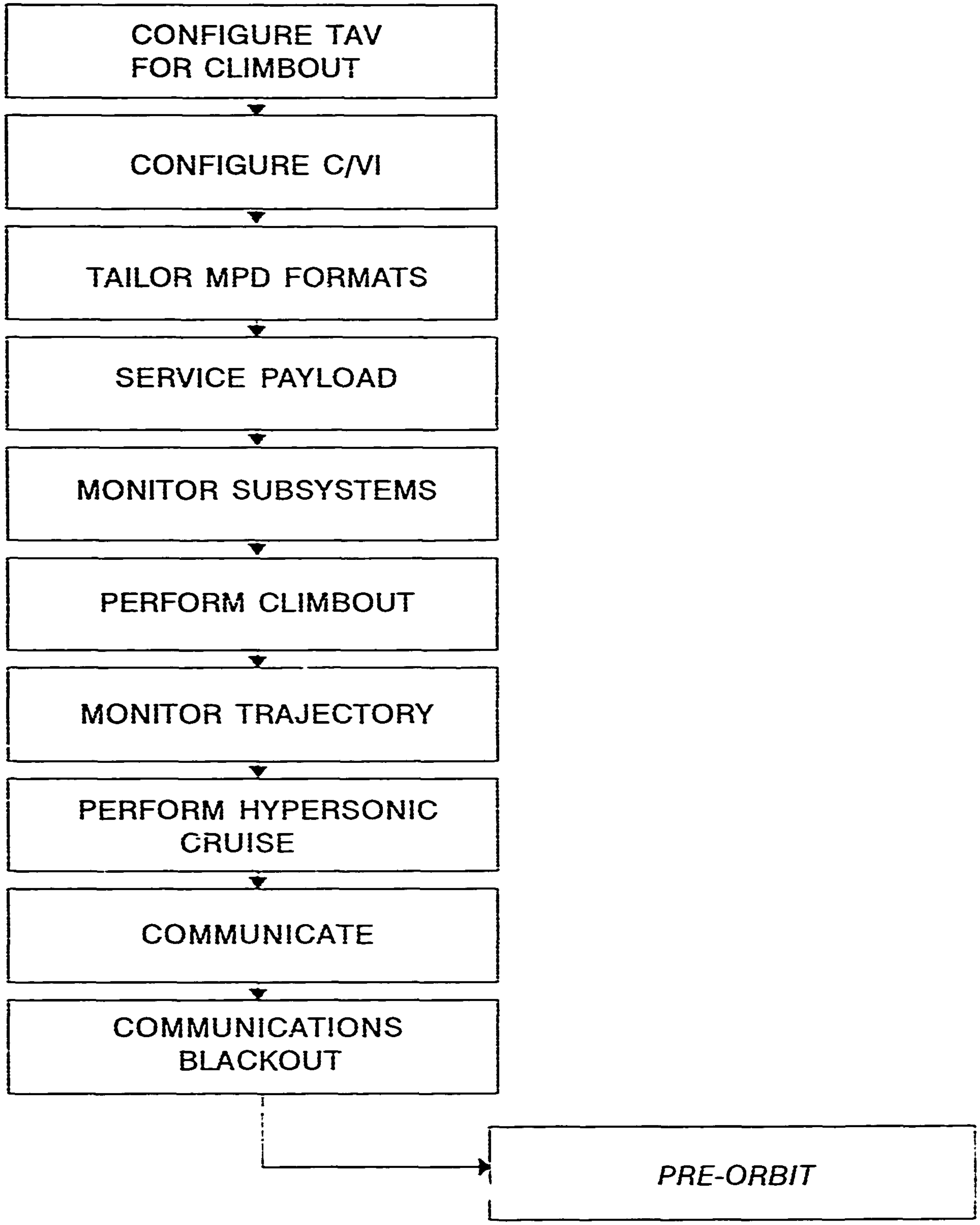

Figure 28. Climbout

As the TAV gains in Mach and altitude, the engines transition to their scramjet mode of operation. The TAV performs hypersonic cruise as it continues to climb and accelerate. The crew communicates progress along the Mission Plan and subsystem status to the Operations Center and establishes initial communication with the mission Command and Control Center. As a high endoatmospheric hypersonic flight profile is achieved, communications blackout is experienced.

Pre-Orbit TAV mission functions (Figure 29) are performed during the last sub-orbital portion of the vehicle's trajectory. The vehicle is configured and the C/VI is configured and the MPD formats are tailored for this flight phase. P/L servicing continues as does subsystem monitoring. As the trajectory becomes exoatmospheric, communications are restored and the crew provides status information to the mission Operations and Command and Control Centers. Trajectory monitoring continues. Fine control inputs are applied to stabilize the vehicle. The TAV is configured for performing a trans-orbital maneuver (if required) and the maneuver is executed. The crew monitors the status of the mission P/L. The TAV performs a climb-to-orbit trajectory maneuver, transitions from scramjet to rocket engine propulsion, achieves a low Earth orbit and ends this phase of the mission.

On-Orbit Operations (Figure 30) comprise the core of the mission. The TAV is configured for P/L operations. The C/VI is also configured and the MPDs are tailored. The P/L servicing continues and the TAV subsystems are monitored. Fine control

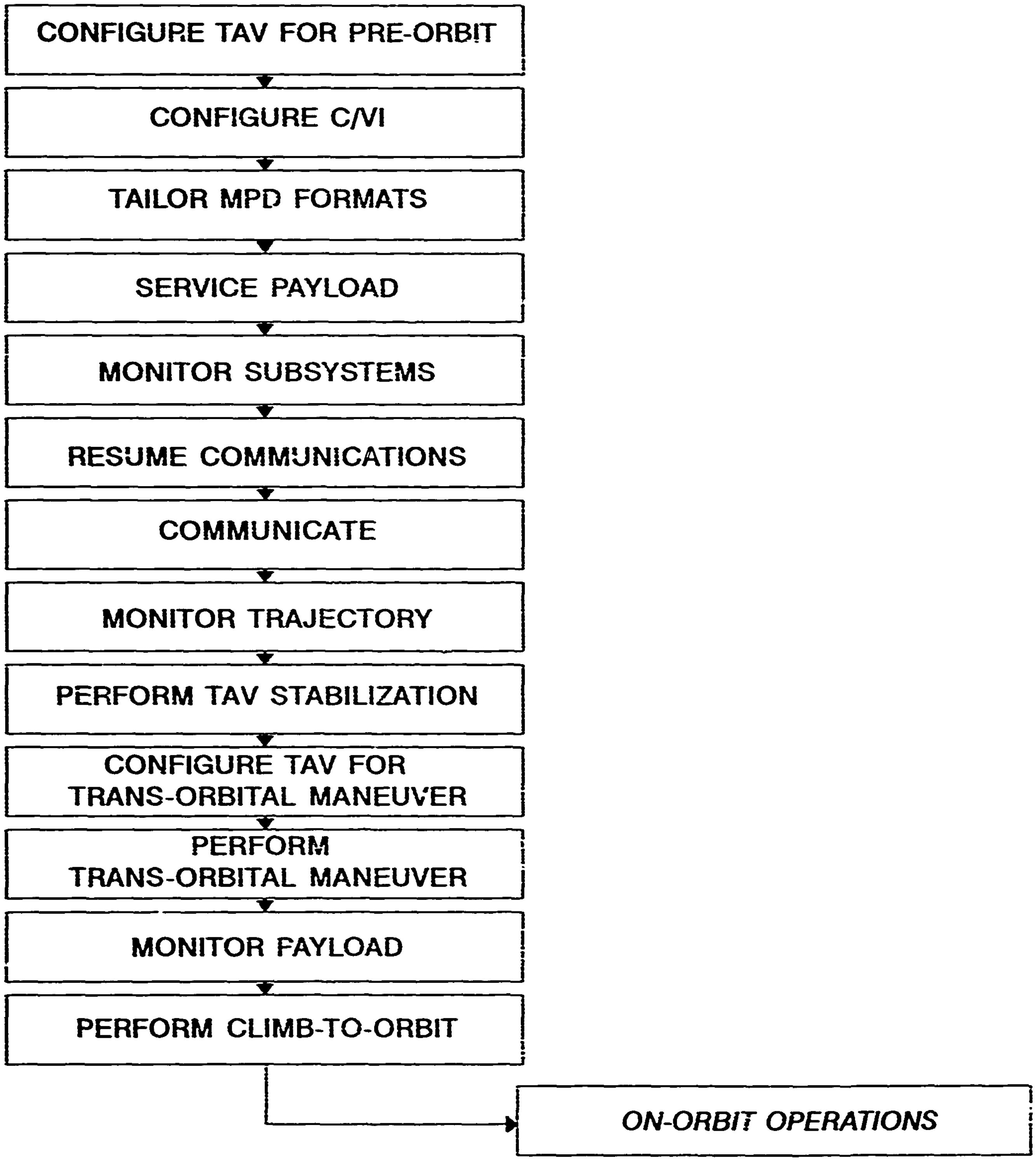

Figure 29. Pre-Orbit

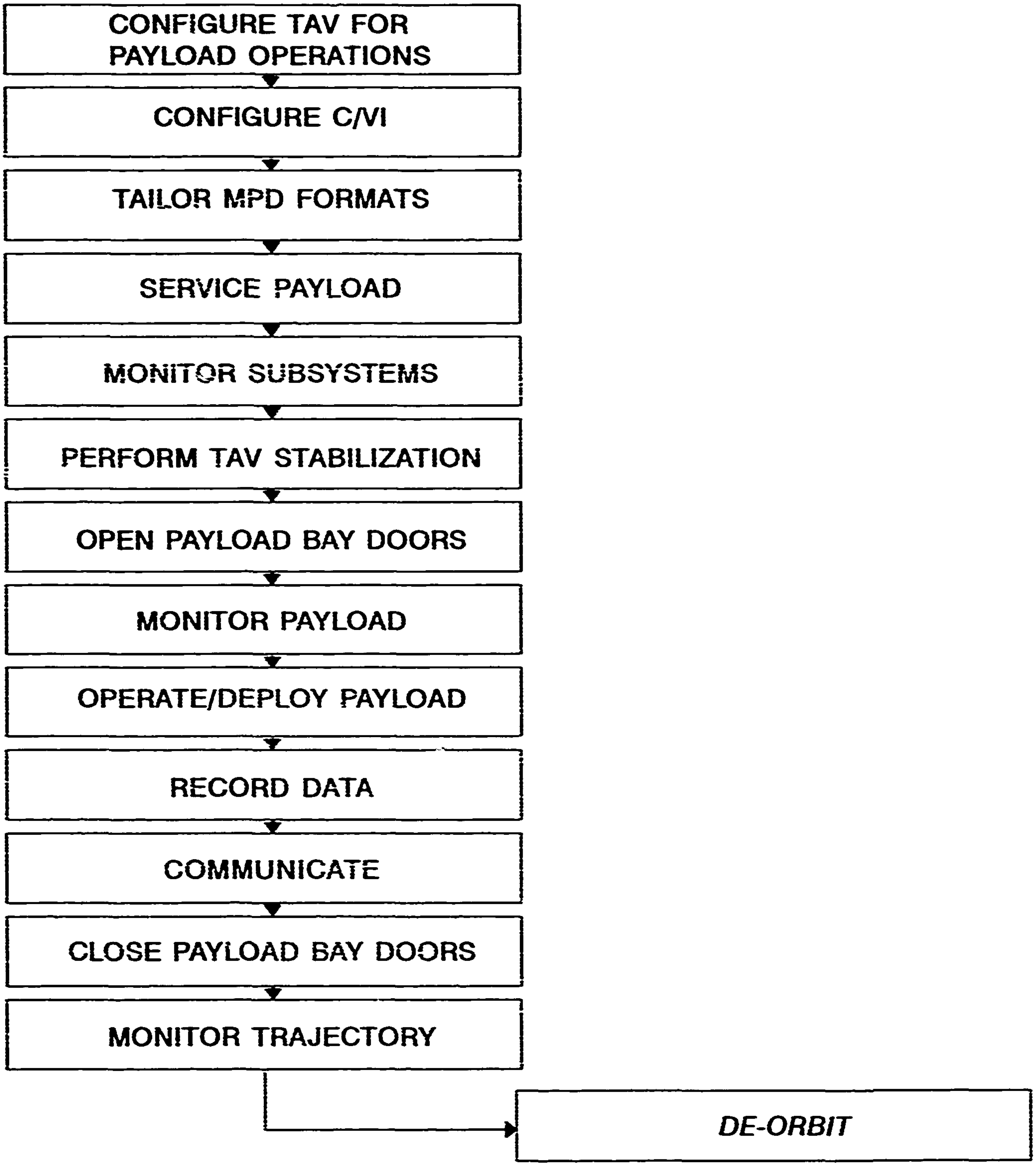

Figure 30. On-Orbit Operations

inputs are applied to the Flight Control Subsystem to stabilize the vehicle using the rocket engines. The crew opens the P/L bay doors. P/L readiness is verified by the crew. As time-on-target is achieved, P/L operations commence. (The specifics of this function depend on the nature of the mission being executed.) P/L and other data are obtained, verified, and recorded. The crew communicates data and system status information to the Command and Control Center. At the conclusion of P/L operations, the bay doors are closed. The crew continues to monitor the orbital trajectory.

At the conclusion of On-Orbit Operations, the crew prepares to De-Orbit (Figure 31). The vehicle and C/VI are configured/tailored for the functions required by the new phase of the mission. Subsystems are monitored and the crew communicates readiness to the appropriate Centers. Rocket engine restart is accomplished and the TAV begins to depart from orbit. The crew monitors the de-orbit trajectory. A second trans-orbital maneuver may be executed as the vehicle departs from orbit. The crew communicates the completion of these events to the Command and Control Center.

The next phase of the TAV mission, Descent (Figure 32), is in many ways the reverse of the Climbout phase. The vehicle and C/VI are configured/tailored. The engine mode is transitioned from rocket to scramjet. The descent is executed with careful attention to dynamic pressure and thermal loading experienced by the airframe. Another trans-orbital maneuver may have been

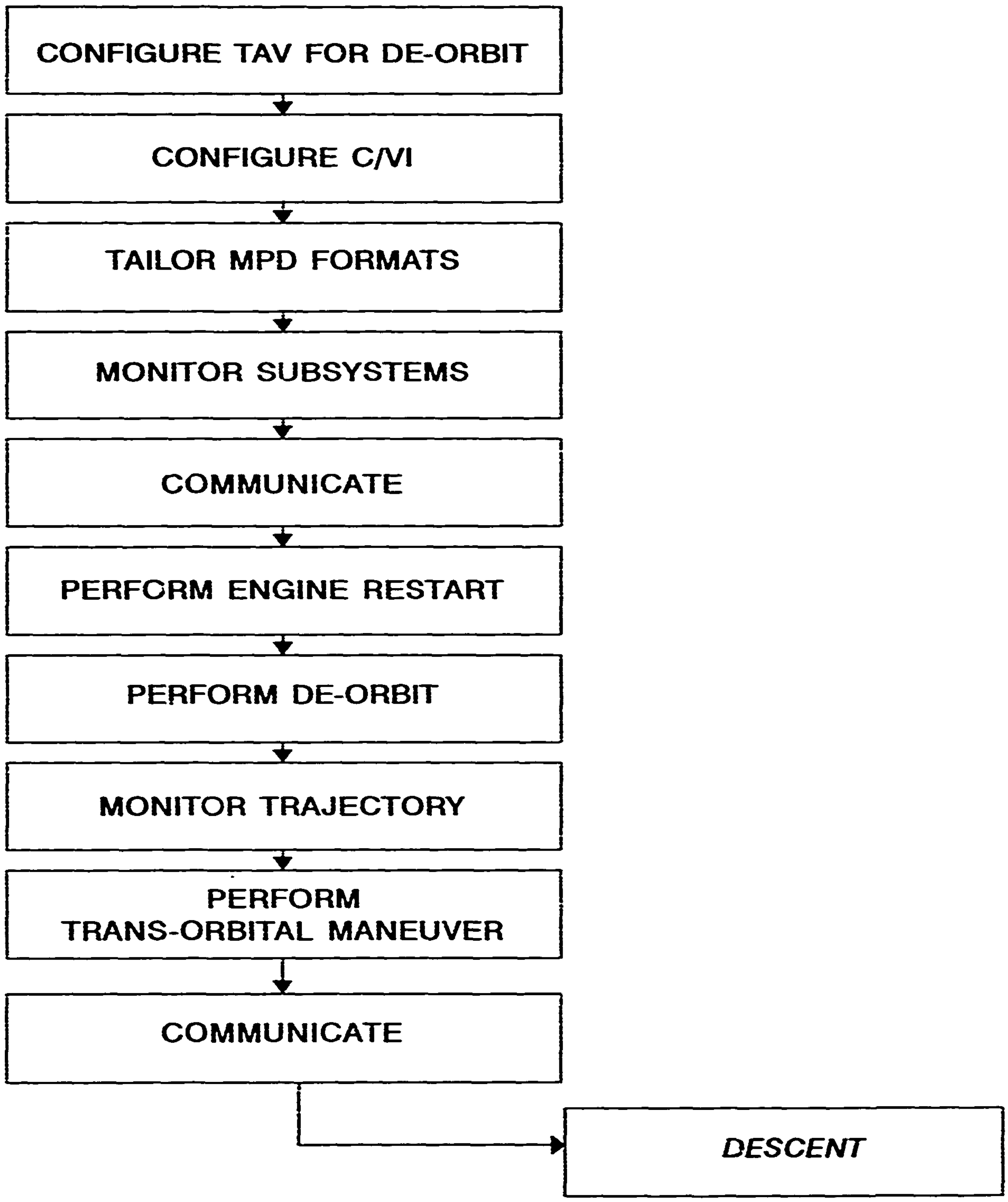

Figure 31. De-Orbit

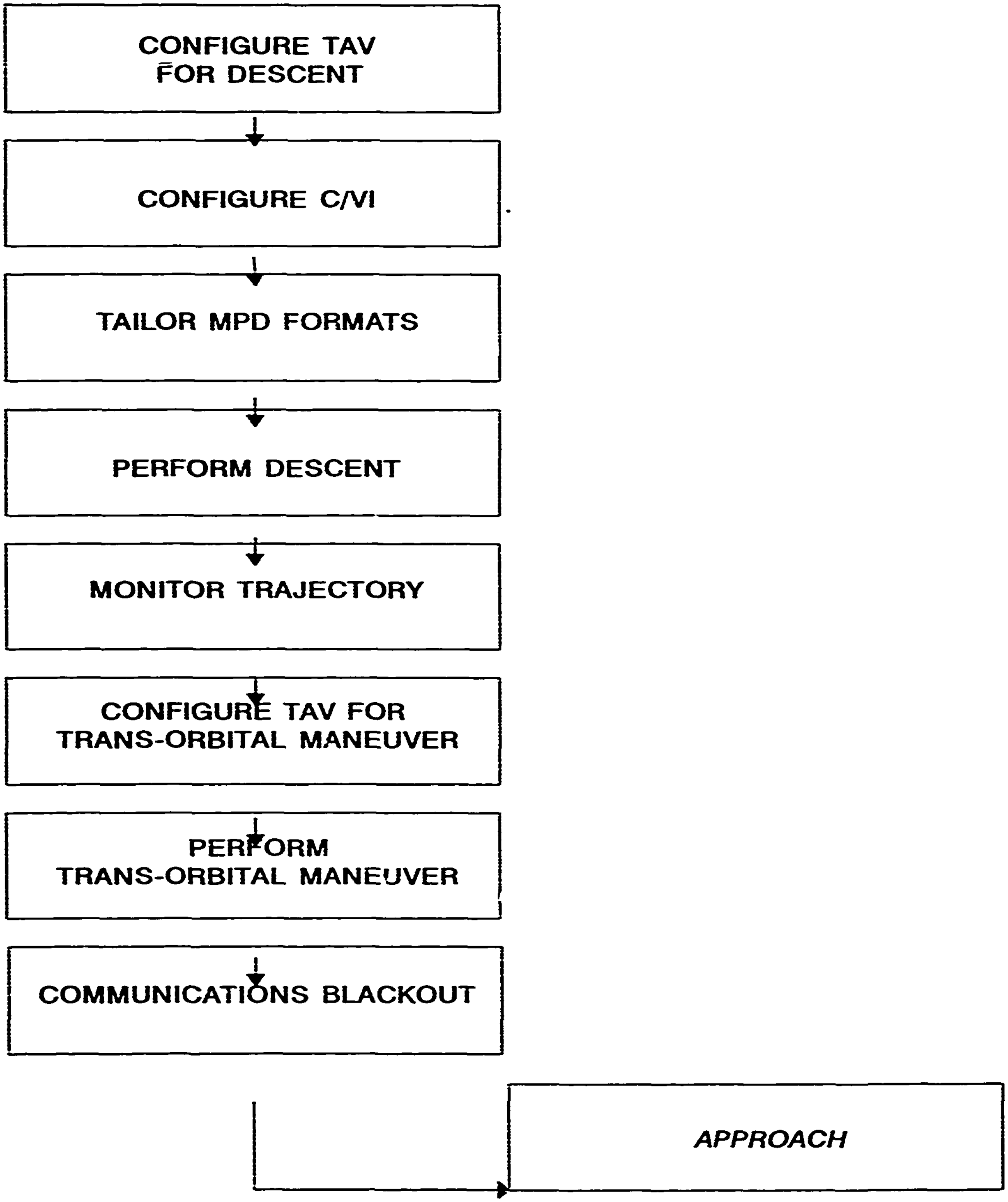

Figure 32. Descent

included in the Mission Plan to allow the TAV to achieve a specified recovery base; if so, the vehicle controls are configured and the maneuver is executed. As the vehicle reenters the atmosphere, a second communications blackout is experienced.

The Approach to the recovery base (Figure 33) is another critical phase of the mission. Configuration and tailoring are performed by the crew. As the vehicle continues to descend and decelerate, the communications blackout ends. The crew can now re-establish connectivity with the Command and Control and Operations Centers. The approach is executed in ramjet engine mode. An extension maneuver may be required (by the Mission Plan) to allow the TAV to achieve the recovery base. If so, it is executed at this time. The crew monitors the alternate recovery bases and trajectories as a safety-of-flight procedure. The crew adjusts the TAV's trajectory and continues to decelerate the vehicle. When the TAV is lined up with the recovery base runway and has achieved nominal flight parameters for landing, the gear is deployed.

Landing (Figure 34) is accomplished in a way very similar to that of a conventional aircraft. The vehicle and C/VI are configured/tailored for this event. Touchdown occurs and the TAV taxis to an assigned location on the airfield. The engines are shut down.

Post-Flight system functions (Figure 35) complete the mission. The crew accomplishes post-flight checklist items and diagnostics are run on all subsystems. Any data recorded during

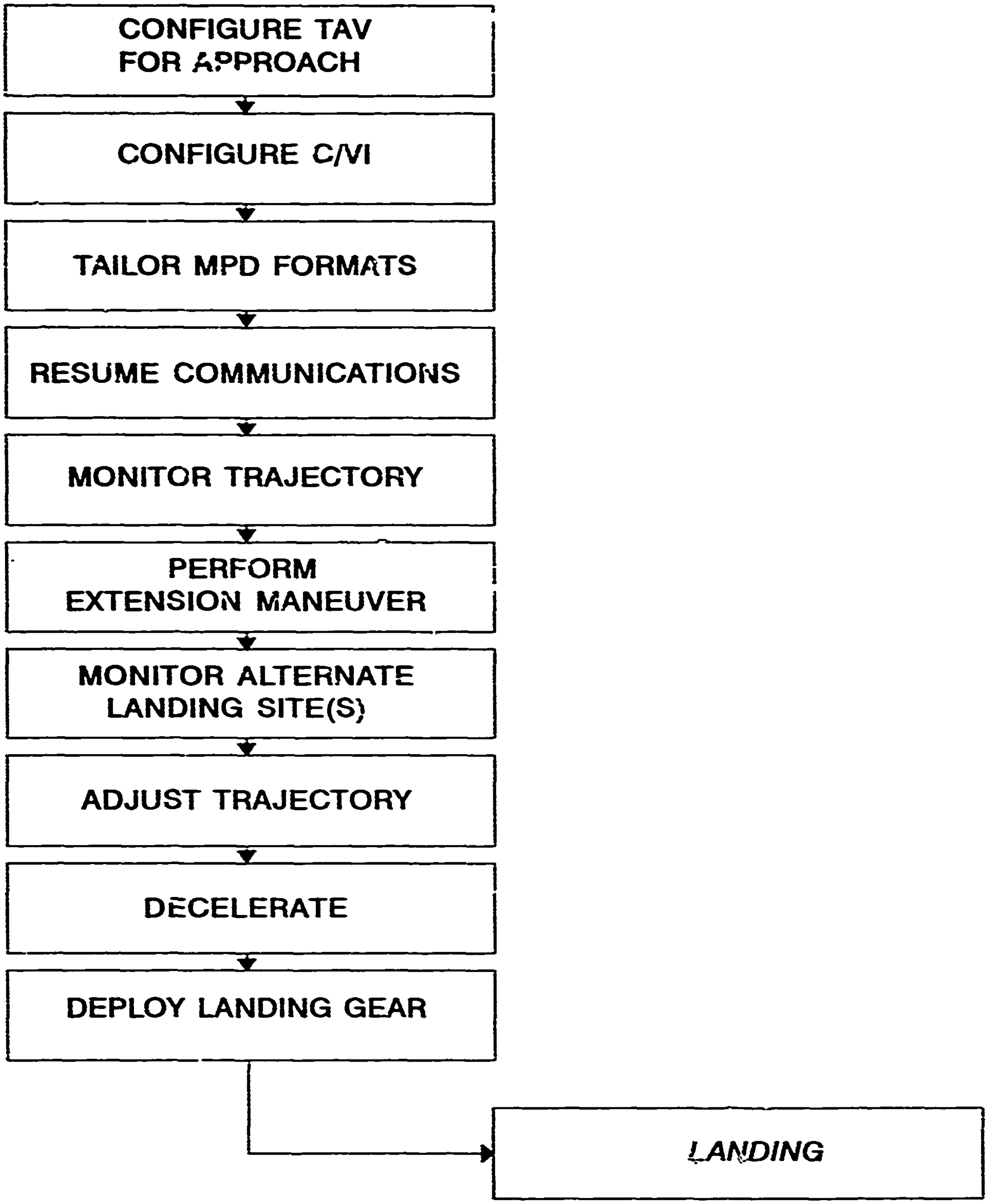

Figure 33. Approach

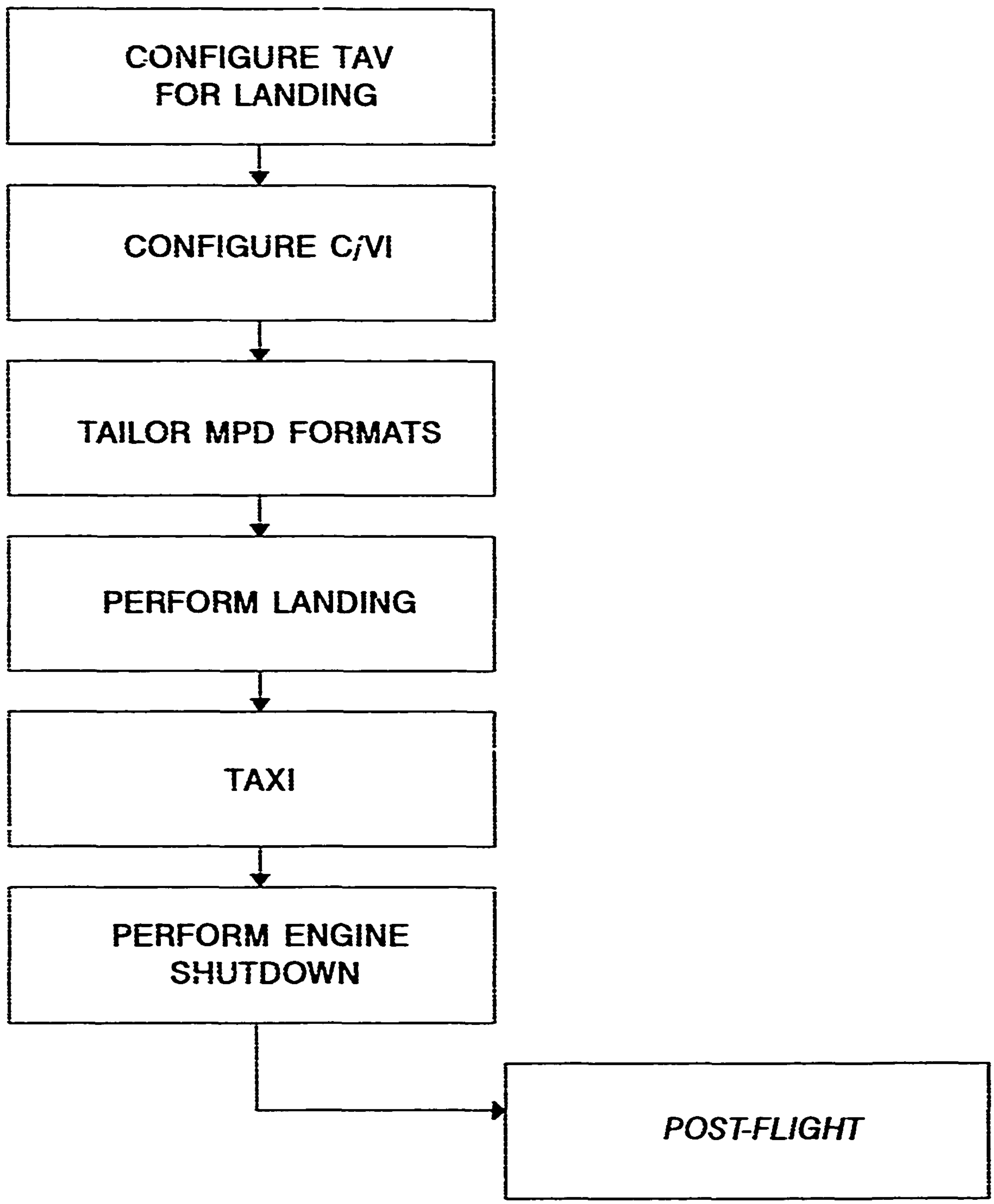

Figure 34. Landing

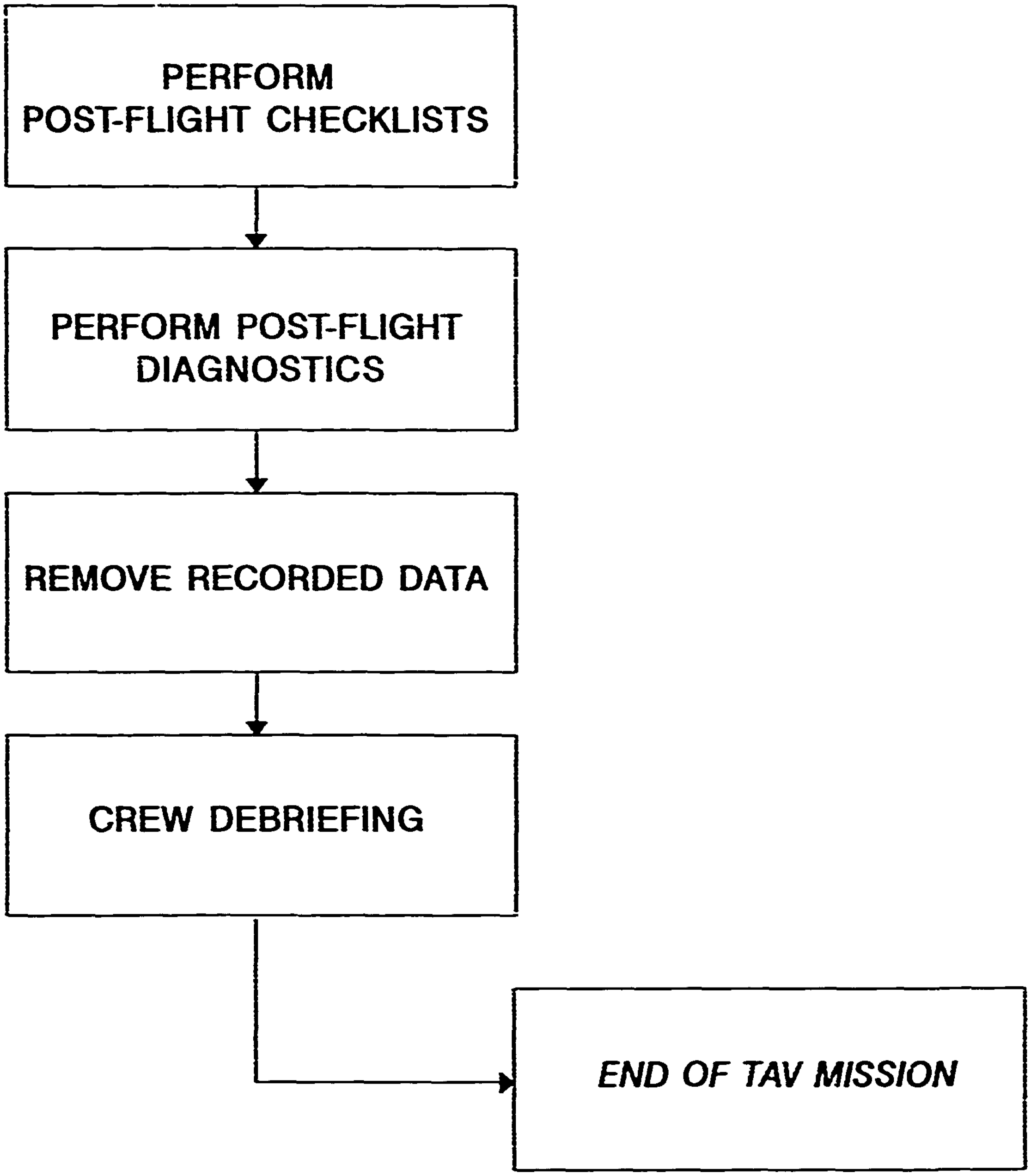

Figure 35. Post-Flight

the mission for post-flight analysis are retrieved at this time. The crew leaves the vehicle and debriefs all aspects of the completed mission.

SECTION IV

TAV SYSTEM ARCHITECTURE

INTRODUCTION

The IDEF0 depictions (function analyses) serve to document the TAV subsystem architecture from the viewpoint of the crew. IDEF0 charts are presented for most of the events enumerated in the MISSION EVENT SEQUENCE. The IDEF0 activity boxes are crew procedures and serve to underscore the active (subsystem operation, payload operation, explicit consent to automated functions, etc.) and passive (monitoring of automated functions, supervisory control of subsystems, establishing and maintaining situational awareness, etc.) contributions of the aircrew to mission accomplishment.

In any highly automated system, many of the system functions are actually executed by the subsystems without overt crew intervention. Routine functions, which are not critical to mission success (e. g., sequencing of mission waypoints on the HSD) are part of normal subsystem operation. The crew is not explicitly notified of their accomplishment but, rather, may see the result of the automated action (e. g., monitoring mission progress on the HSD). In other cases, the concept of "implied consent" may guide the automation (e. g. automatic flight control). In this case, the automation will accomplish a procedure <u>unless</u> the crew elects to intervene. The system architecture then includes capabilities for manual override. The

crew can disable the automated function by simply electing to perform the action through a direct, manual intervention with the subsystem (e. g., flight control inputs applied through the stick and/or throttle). A third automation integration concept reflected by the TAV architecture is "management by exception." In this case, the automation will perform selected functions unless an "out-of-nominal" condition is encountered, in which case it will act to inform the crew and to elicit a manual intervention. The "SELF-HELP" SUBSYSTEM is an example of management by exception.

In the IDEF charts, the frequent occurrence of SOP as a Control element is intended to reflect both the standard procedures/checklists performed by the crew and the automated functioning of the TAV subsystems. In the latter case, the specific subsystem(s) is identified as a Mechanism for task accomplishment.

The IDEF functions are abstracted from the Mission Event Sequence (MES). Each function is graphically depicted in the IDEF0 convention. Accompanying text describes the execution of the function in detail.

Many of the functions (e. g., CONFIGURE THE C/VI) are performed repeatedly in the MES. From the standpoint of the IDEF charts, these functions may be thought as being "subroutines" which are called when their execution is required.

IDEF0 DEPICTIONS

The IDEF0 depictions and their accompanying explanatory text are presented in the order in which the TAV System Functions appear in the MES, beginning with the Takeoff phase of the mission. These IDEF0 representations cover the TAV System Functions of CONFIGURE TAV FOR (FLIGHT MANEUVER), which is a repeated function first encountered during Takeoff, through PERFORM ENGINE RESTART, which is performed during the De-Orbit mission phase.

Additional TAV System Functions, not listed in the MES (which was prepared for a notional mission), but which reflect significant system capabilities are appended. These additional TAV System Functions are:

ADJUST TRAJECTORY (MANUAL)
COMMUNICATE: RECEIVE
UPDATE MISSION PLAN
UPDATE PAYLOAD GUIDANCE AND CONTROL
RESPOND TO WCA

TAV System Function: CONFIGURE TAV FOR (FLIGHT MANEUVER)

This IDEF depiction is intended to serve as a generic model for all "Configure TAV" activities listed in the MES. Vehicle configuration, primarily a monitoring task with manual override provisions, is performed prior to any change in the type of trajectory about to be accomplished: Takeoff, Climbout/Ascent to Orbit, Pre-Orbit, Trans-Orbital Maneuver, On-Orbit Payload Operations, De-Orbit, Descent, Approach, and Landing. Configuration consists of setting and verifying the position of any multi-position flight control surfaces on the vehicle (e. g., the wing sweep on a B-1B bomber). Configuration changes are automated. The FLIGHT CONTROL SUBSYSTEM, with its subsidiary TRAJECTORY MANAGER, uses data obtained from the MDL and TAV PERFORMANCE CHARACTERISTICS DATA BASES, by the DATA MANAGEMENT SUBSYSTEM, to effect the required control surface (re)configuration.

It is assumed that the C/VI has already been configured for the mission phase. Further, the C/VI has been tailored to bring up the Flight Control Subsystem MPD Format screen on one of the MPDs.

The crewmember uses the BEZEL BUTTONS to call up the TAV Configuration MPD Format screen, a secondary screen to the Flight Control Subsystem MPD Format screen. The crewmember observes the TAV configuration. Based on his situational awareness (derived from mission plan information on the VSD and HSD), he determines if the vehicle configuration is correct for the upcoming

trajectory change. If an "out-of-nominal" configuration is observed, he can use the BEZEL BUTTONS to manually achieve the proper configuration.

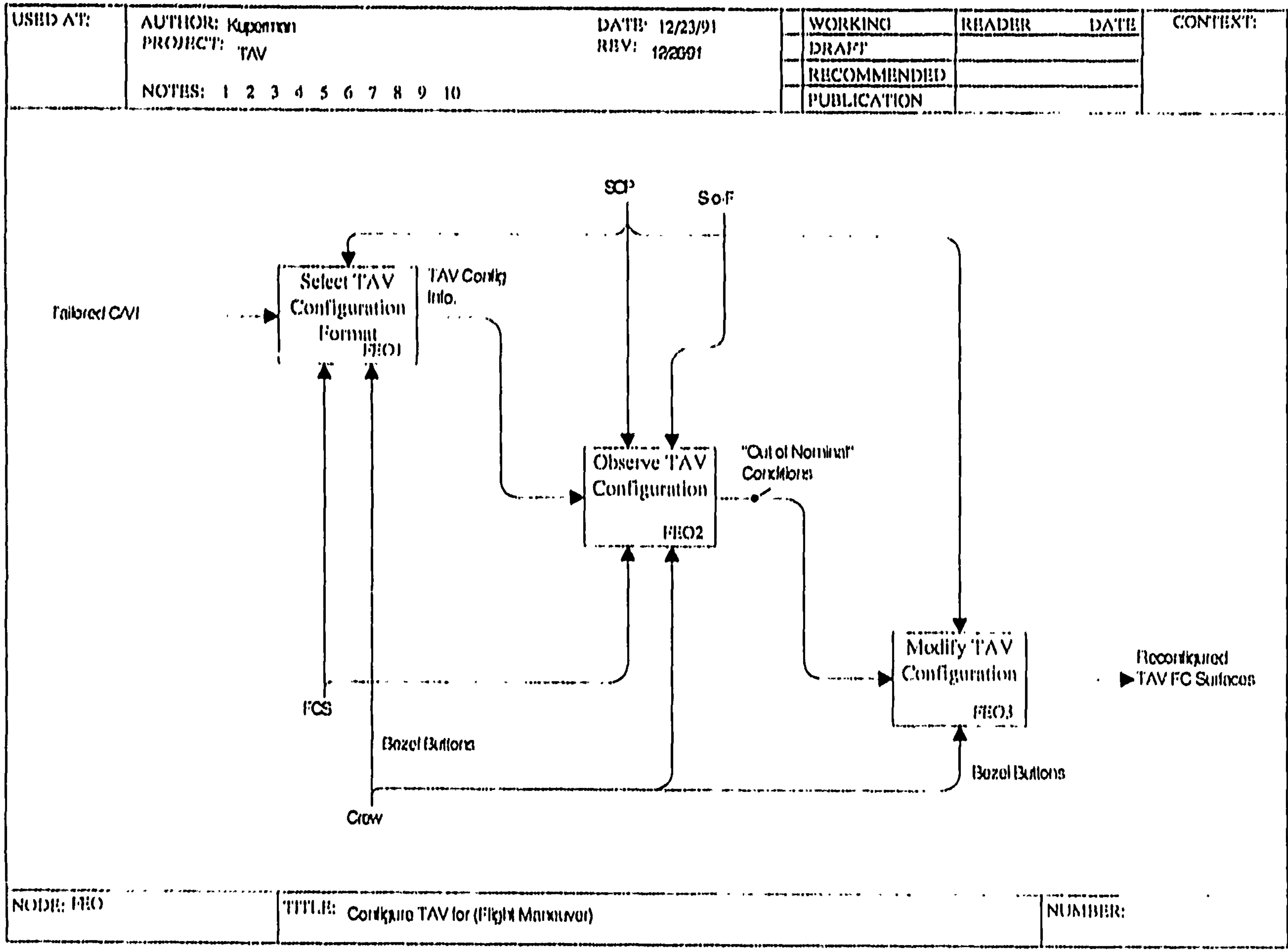

Figure 36. Configure TAV for (Flight Maneuver)

TAV System Function: CONFIGURE THE C/VI

The TAV crew system is comparable to that found in a modern fighter or bomber aircraft. The crew system concept includes minimizing the number of switch activations required to obtain information or to perform a subsystem control action. This design goal is intended to reduce crew workload. Another design assumption is that (at least) one TAV crewmember has the VSD (primary flight control) and HSD (primary situational awareness) format screens active on his MPDs. This assumption supports the crew in mission pacing (preparing for and executing crew tasks in a timely sequence and avoiding the creation of task backlogs). A third design assumption is that one crewmember is always serving as "pilot-in-command," with primary responsibilities of flight execution and safety-of-flight monitoring, while the second crewmember is responsible for subsystem and payload operations. It is assumed that both crewmembers are cross-trained, i. e., that each crewmember can accomplish all crew tasks with approximately equal proficiency. Hence, another design consideration is that any format screen (subsystem display and controls) can be activated on any MPD at either crew position. It is assumed that each mission phase, essentially by definition, will encompass a series of functions which are related to the specific objectives of that phase. It is further assumed that mission priorities (i. e., the relative importances of functions and tasks) will be modified for each phase of the TAV mission.

The crew monitors the mission on the VSD and HSD screens. Current status data, along with Mission Plan information (obtained from the MDL), are reviewed as a continuous monitoring function. The crew notes that a mission phase transition (e. g., completing Climbout and beginning Pre-Orbit) is about to take place. The crew employs the MASTER MODE selection buttons to reconfigure the crew system. A single control input (MASTER MODE button depress) changes the subsystem format screens on all of his MPDs. The general guideline for how the new screens are arranged is derived from Tactical Doctrine. The response of the C/VI to a MASTER MODE control input is preset (stored in an on-board, permanent data base), and can be tailored to reflect individual crewmember preferences (including crew confidence), or mission-specific special operational procedures, or rules of engagement. The specifics of the new C/VI configuration depend on the new mission phase to be executed. Lastly, the crewmember verifies that the expected C/VI response has, in fact, occurred.

It is assumed that MASTER MODE changes would not be automated. A sudden, unexpected reconfiguration of the C/VI could be disorienting to a crewmember. Each crewmember performs the C/VI configuration independently. It is also assumed that the TAV crew will perform MASTER MODE changes in sequence. One crewmember will input the change and verify the correct system response before the second crewmember accomplishes the same function. This would support safety-of-flight considerations. It would also allow one crewmember to continue to monitor the

current/last mission phase while the second crewmember prepares for/begins the new one.

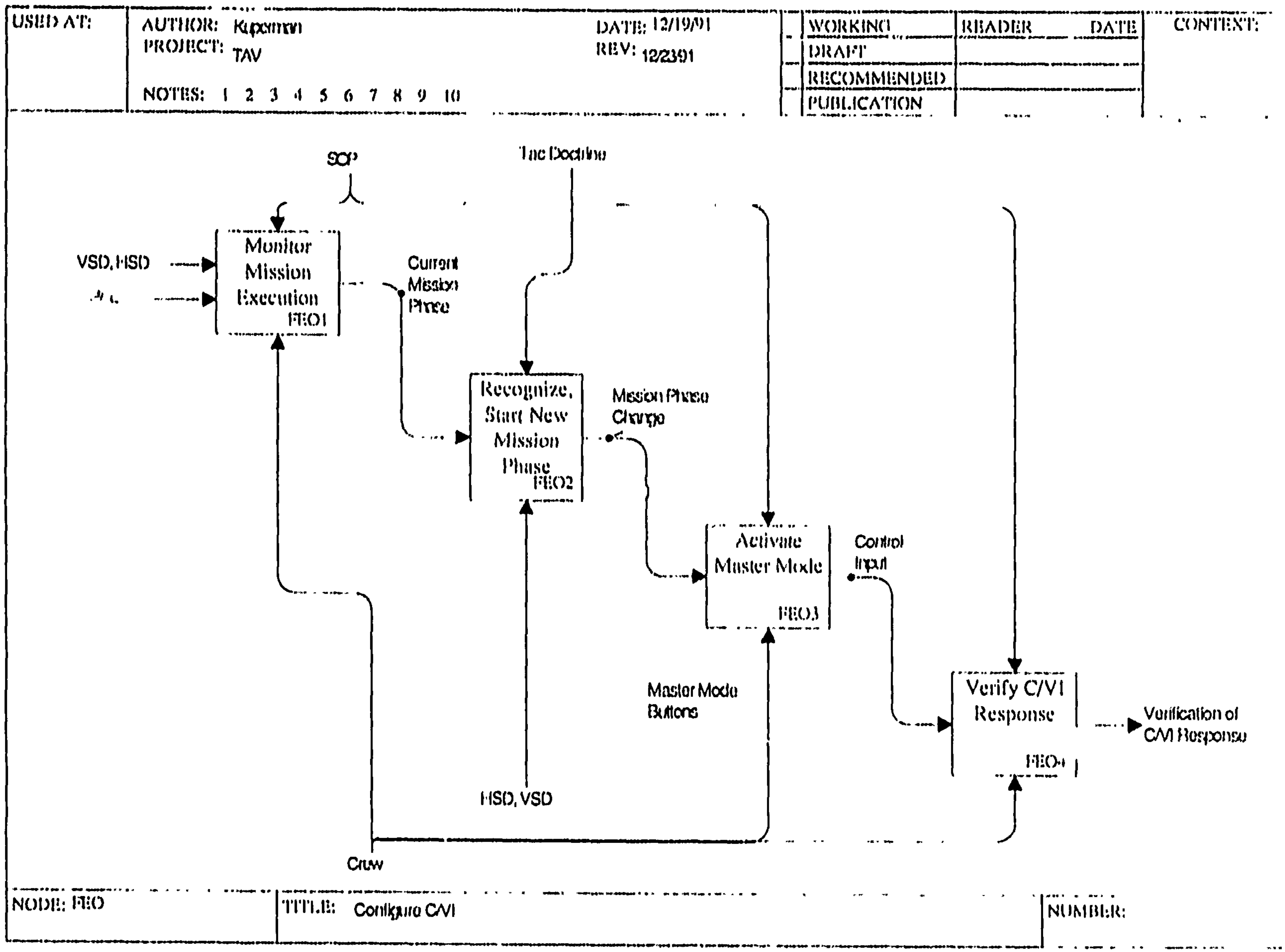

Figure 37. Configure C/VI

TAV System Function: TAILOR MPD FORMATS

In designing the TAV crew system concept, it is assumed that any information source (Subsystem MPD Format) is available on any display surface (MPD) at any time during the mission. The TAV crew system is assumed to be a "Glass Cockpit" with few dedicated controls or displays. Information is obtained and subsystem controls are accessed by means of the MPD Formats screens. The specific arrangement of formats and the level of an individual subsystem being accessed are controlled through the crewmember's "tailoring" of the MPD formats. It is assumed that some changes to the MPD format screens will probably be required for the accomplishment of each task in the MES.

The crew maintains awareness of current and upcoming mission events by monitoring the VSD and HSD situational awareness display screens. These screens depict the Mission Plan events. When the crew identifies an upcoming (next) mission event, he employs the BEZEL BUTTONS to change the subsystem represented on an MPD (using the Subsystem Menu MPD Format to select a new subsystem) and/or to change the level at which he is interacting with the current subsystem (e. g., select and activate a secondary level Subsystem MPD Format screen). The crew verifies that the expected format has been presented to him.

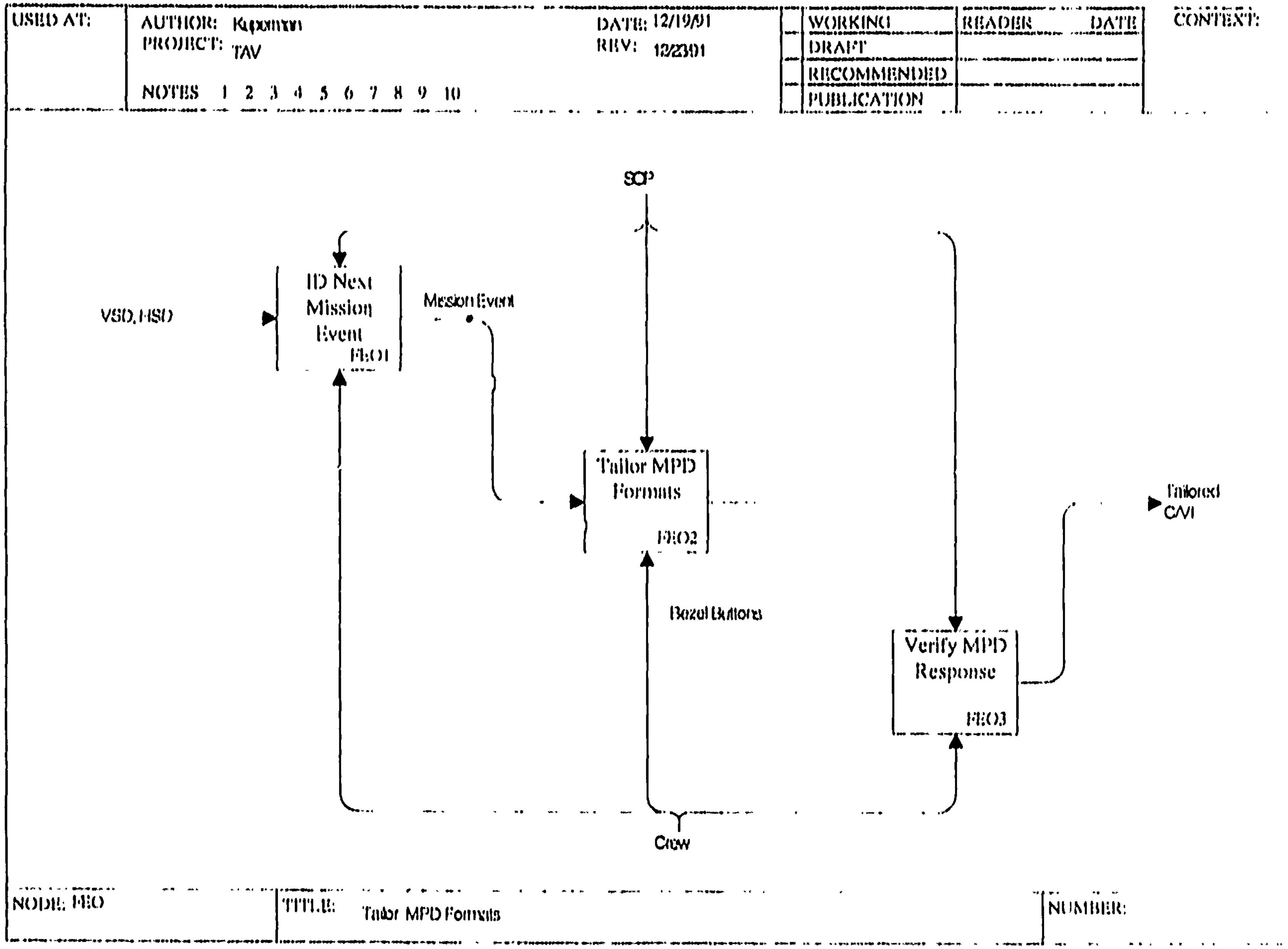

Figure 38. Tailor MPD Formats

TAV System Function: MONITOR ENGINES

The TAV's ramjet, scramjet and rocket engines are fully integrated into the vehicle's aerodynamic design. During airbreathing mission phases, a portion of the vehicle underbody provides precompression of the airstream as it enters the engine inlet and a portion of the aft underbody forms the engines' exhaust nozzle. The engine modes transition automatically between ramjet and scramjet operation and in and out of rocket propulsion under the control of the ENGINE MANAGEMENT SUBSYSTEM. These transitions take place as a function of vehicle Mach number and altitude. Engine monitoring is perhaps most critical during these engine mode transition events.

The crewmember observes current engine performance by tailoring the C/VI to activate the Engine Management Subsystem MPD Format screen. Given the throttle settings and engine mode, the crewmember observes the actual thrust and efficiency values on the MPD screen. This format also provides the expected (or nominal) engine performance values. Nominal values are obtained from the Engine Performance portion of the TAV Flight Characteristics Data Base by the DATA MANAGEMENT SUBSYSTEM and are presented as comparative indices on the Engine Management Subsystem MPD Format screen. The crewmember observes the actual engine performance and compares it against the expected values.

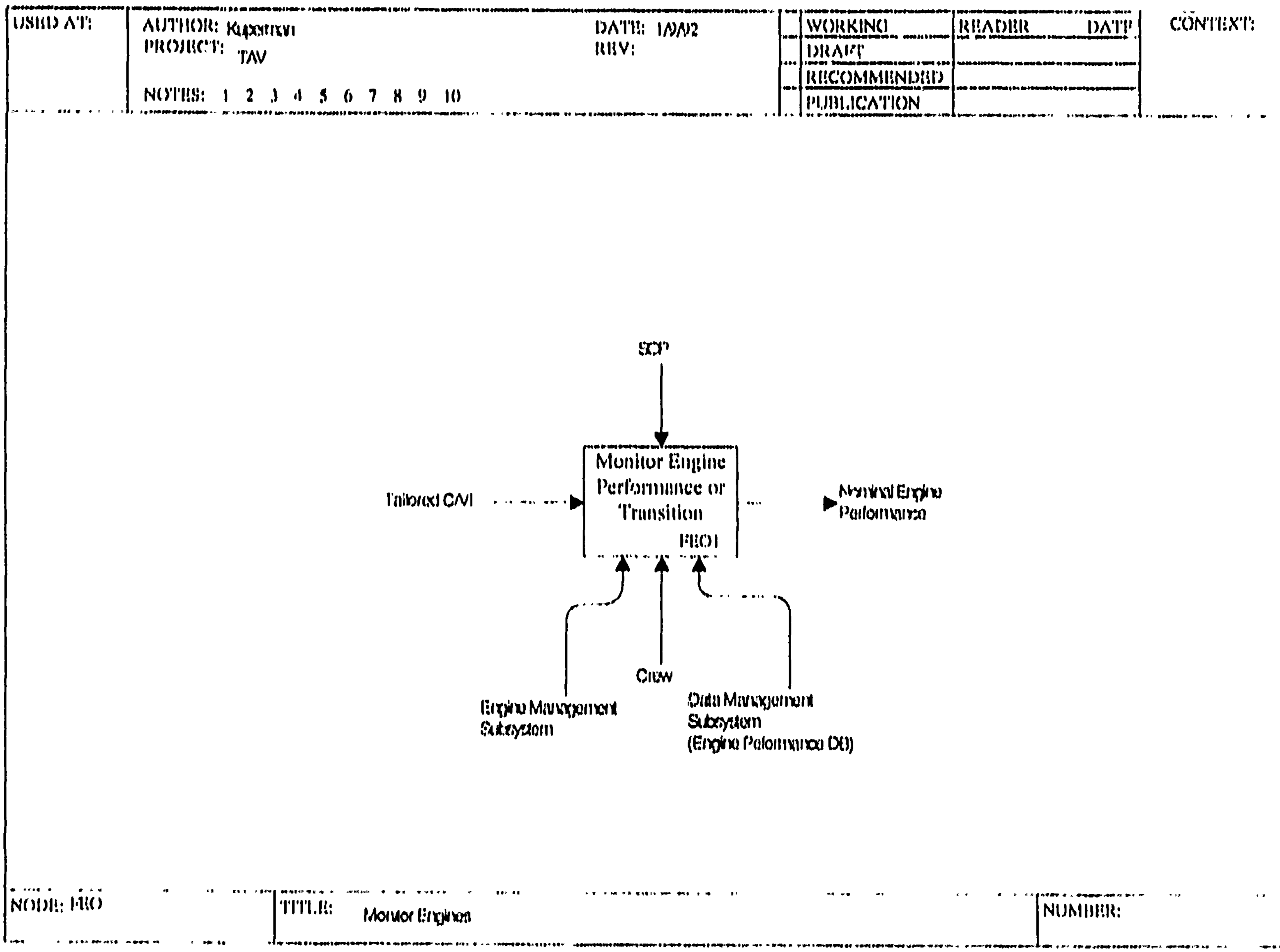

Figure 39. Monitor Engines

TAV System Function: SERVICE PAYLOAD

Many of the TAV missions are based on the capabilities provided by mission payloads which are either operated while on-board the TAV or are placed into orbit. Mission success, then, frequently depends on attaining orbit with a "healthy" payload (or combination of payloads). The TAV provides payload servicing from the moment that the payload is installed in the payload bay until it is either deployed or removed (during Post-Flight). Payload servicing is automated and consists of providing heating/cooling, power, gases or liquids, etc., and replenishing payload consumables. The containerized payload is mated to the TAV's payload interface. All payload services are provided across this interface. The monitoring of container and payload status is also accomplished through this interface. The PAYLOAD INTERFACE SUBSYSTEM performs payload servicing. The crew monitors payload status and (manually) intervenes only if the automation results in a deviation from nominal payload servicing requirements.

Payload servicing status information is monitored on the Payload Interface Subsystem MPD Format screen. Current payload state information is provided by sensors either within the payload itself, the payload container, or the Payload Interface. Payload servicing requirements information is provided by the TAV's DATA MANAGEMENT SUBSYSTEM from the PAYLOAD SERVICING REQUIREMENTS DATA BASE. The crew identifies any deviations between payload servicing status and servicing requirements. If

a deviation is found, the crew activitates (BEZEL BUTTONS) the Payload Interface Service MPD Format screen, a subsidiary format to the Subsystem Format screen. The crew can then adjust the servicing by selecting a service (BEZEL BUTTONS) and employing increment/decrement BEZEL BUTTONS to modify the rate/level of that service. This is continued until actual payload servicing status agrees with nominal payload servicing requirements.

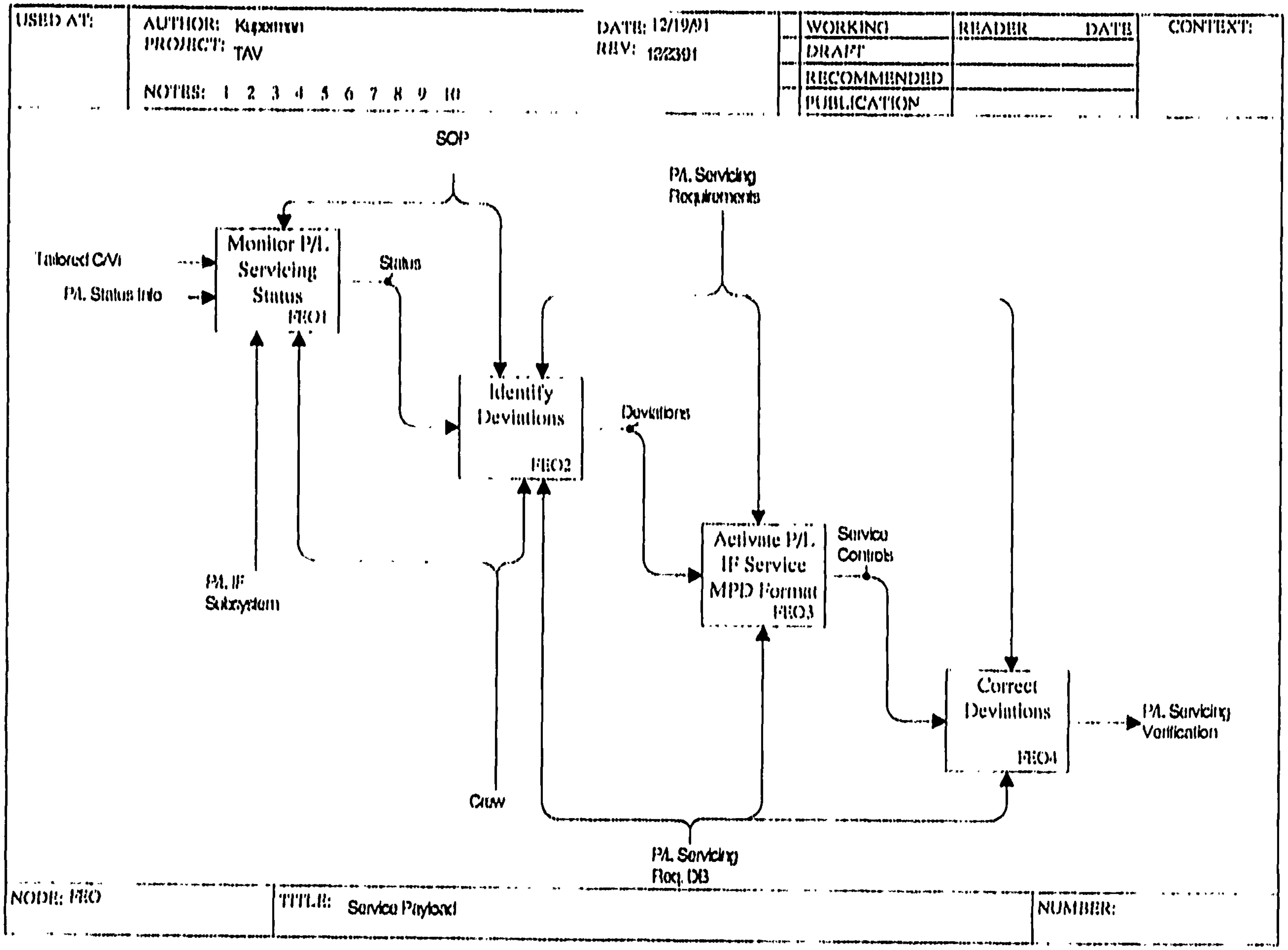

Figure 40. Service Payload

TAV System Function: MONITOR SUBSYSTEMS

The Subsystems MPD Format screen is a unique information display. The crew can activate this screen at any point in the mission and on any MPD surface. This screen depicts the current status of each TAV subsystem. The status information includes subsystem operational state (ON/STANDBY/OFF), utilization (percent subsystem capacity actually being employed), and other "top level" operating information. The crewmember can quickly verify nominal (or quickly identify out-of-nominal) subsystem status.

The Subsystems MPD Format is an "own-ship" status information display. If the TAV has been reconfigured (e. g., for a degraded mode of operation), this information will be readily noted from this format screen. It primarily supports crew situational awareness in this area. It is also a (manual) complement to the "SELF-HELP" SUBSYSTEM in this regard. Secondary screens, accessed through the Subsystem MPD Format, allow the crewmember to control each subsystem operational state and moding.

The control functions associated with this format allow the crewmember to select individual Subsystem MPD Format screens. These screens provide more detailed information regarding specific subsystem operation and allow the crewmember to perform BIT, change operational states, and change subsystem moding.

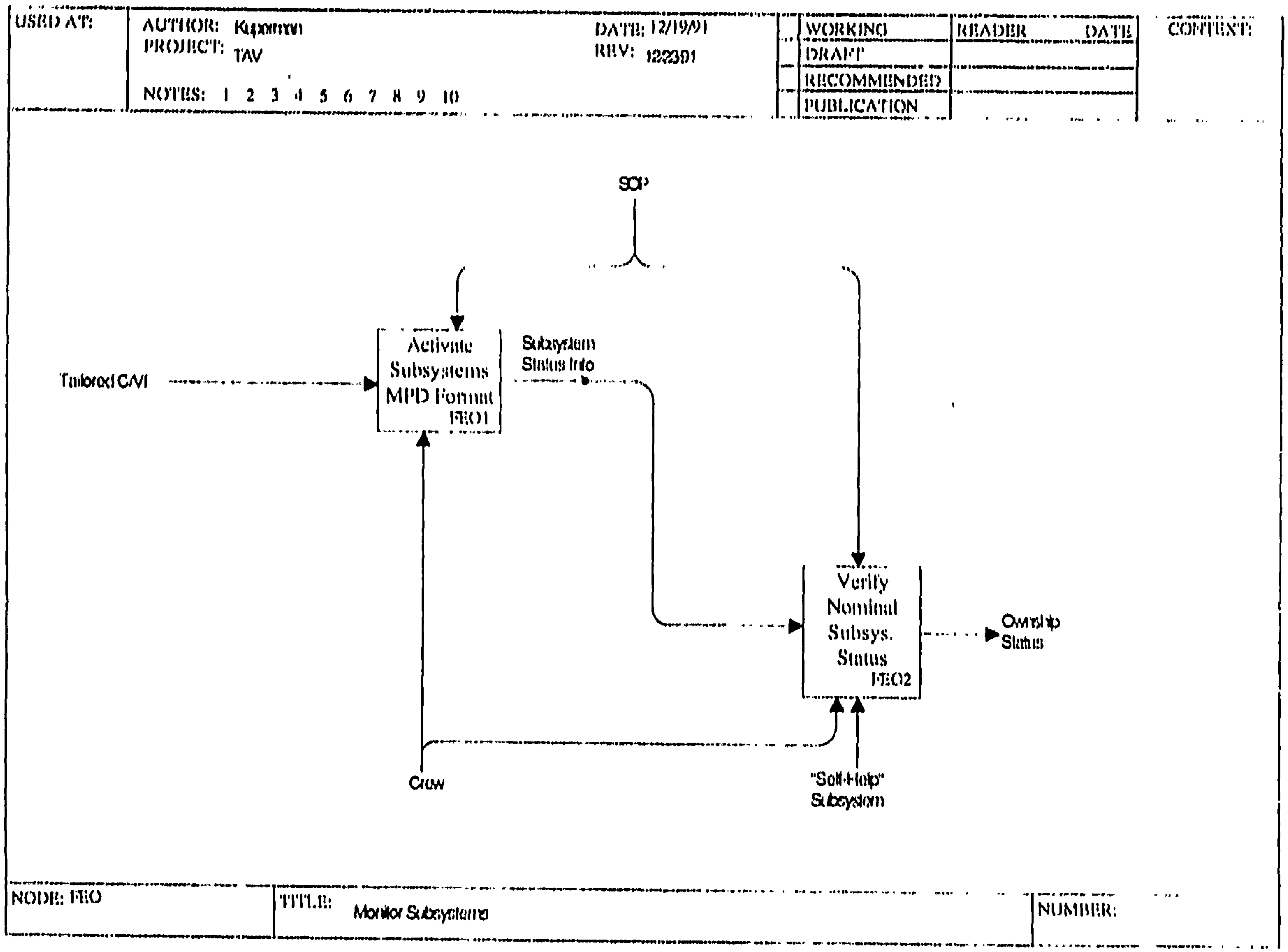

Figure 41. Monitor Subsystems

TAV System Function: PERFORM (FLIGHT) MANEUVER

The TAV is capable of executing a number of flight/ trajectory control maneuvers during each phase of the mission. These maneuvers include: Takeoff, Climbout, Pre-Orbit, Ascent (to orbit), De-Orbit, Descent, Approach, and Landing. Hypersonic cruise is performed/maintained in the Climbout and Descent phases of the MES. Additionally, one or more Trans-Orbital maneuvers may be included in the mission execution. (A Trans-Orbital Maneuver may be required, for example, to match the TAV's trajectory to that of an orbiting space asset for recovery, repair, resupply, etc.) An extension maneuver may be required during the Descent or Approach phases to allow the TAV to recover to an alternate recovery base.

The execution of flight maneuvers is automated. The TRAJECTORY MANAGER of the FLIGHT CONTROL SUBSYSTEM monitors the current TAV state vector (altitude, Mach, Latitude/Longitude, inclination, ascension, etc.) and continuously computes a trajectory which will achieve the desired/required state vector. The FLIGHT CONTROL SUBSYSTEM uses the (re)planned trajectory to automatically control the engines and flight control surfaces so as to accomplish the trajectory. Additionally, the FLIGHT CONTROL SUBSYSTEM generates flight director commands (which appear on the VSD) to provide the crew with safety-of-flight information in the event that manual flight control intervention is required. (See TAV System Function: MONITOR TRAJECTORY.)

The crew, primarily the pilot-in-command, monitors the

FLIGHT CONTROL SUBSYSTEM's execution of the required maneuver. The VSD depicts Mach, altitude, trajectory, and flight director information. Latitude/Longitude, mission phase transition point, inclination, and (primary and alternate) recovery base information is presented on the HSD. The Engine Management MPD Format screen presents engine performance data. The Dynamic Pressure and Thermal Loading MPD Format screens provide additional vehicle state data.

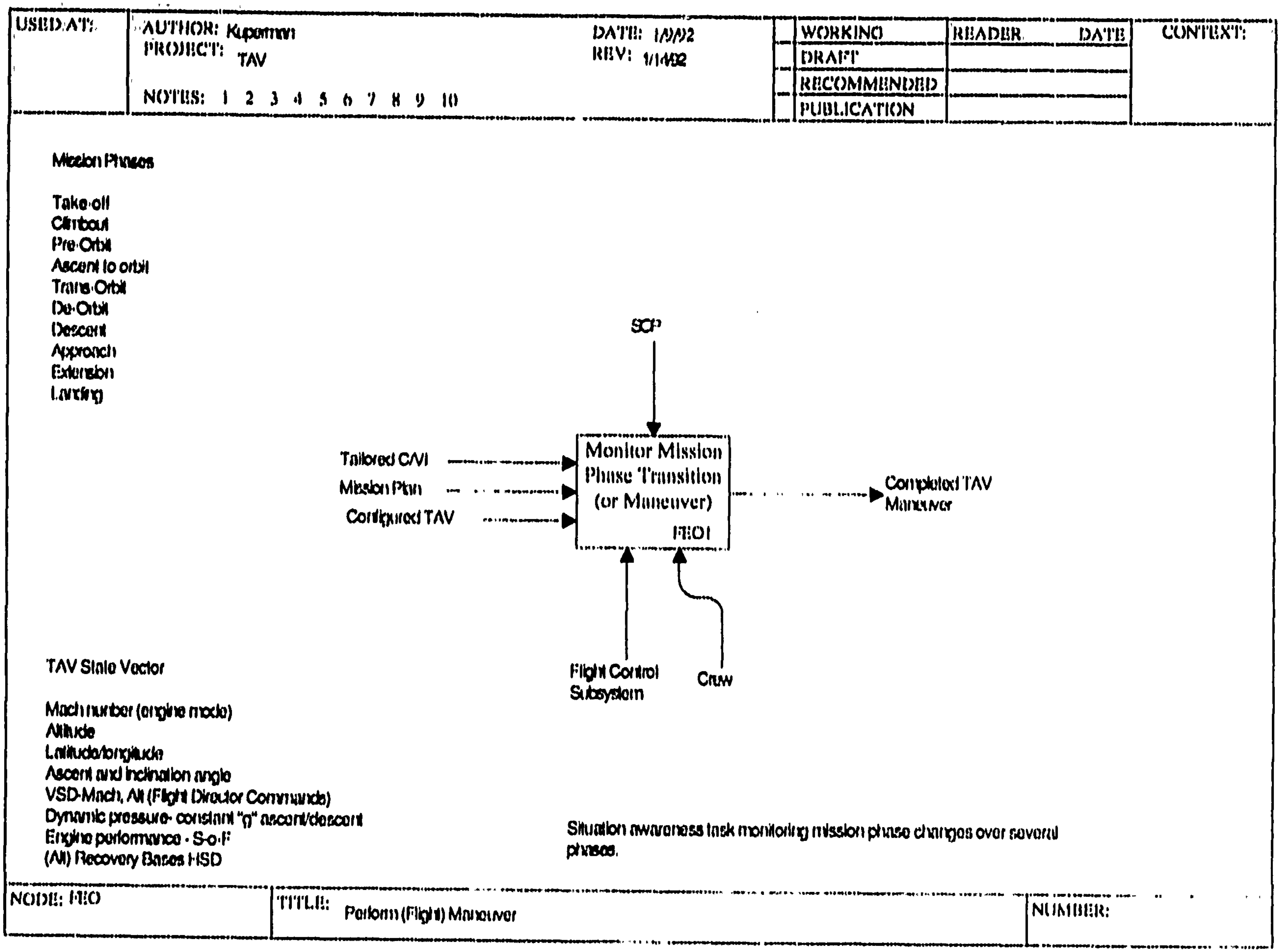

Figure 42. Perform (Flight) Maneuver

TAV System Function: RETRACT/DEPLOY LANDING GEAR

The TAV's landing gear are retracted immediately upon crew assurance that a safe Takeoff has been accomplished. They are deployed during the Approach phase of the mission upon crew assurance that a within-nominal final approach to the recovery base is being accomplished. A dedicated, panel-mounted control is assumed to effect this function.

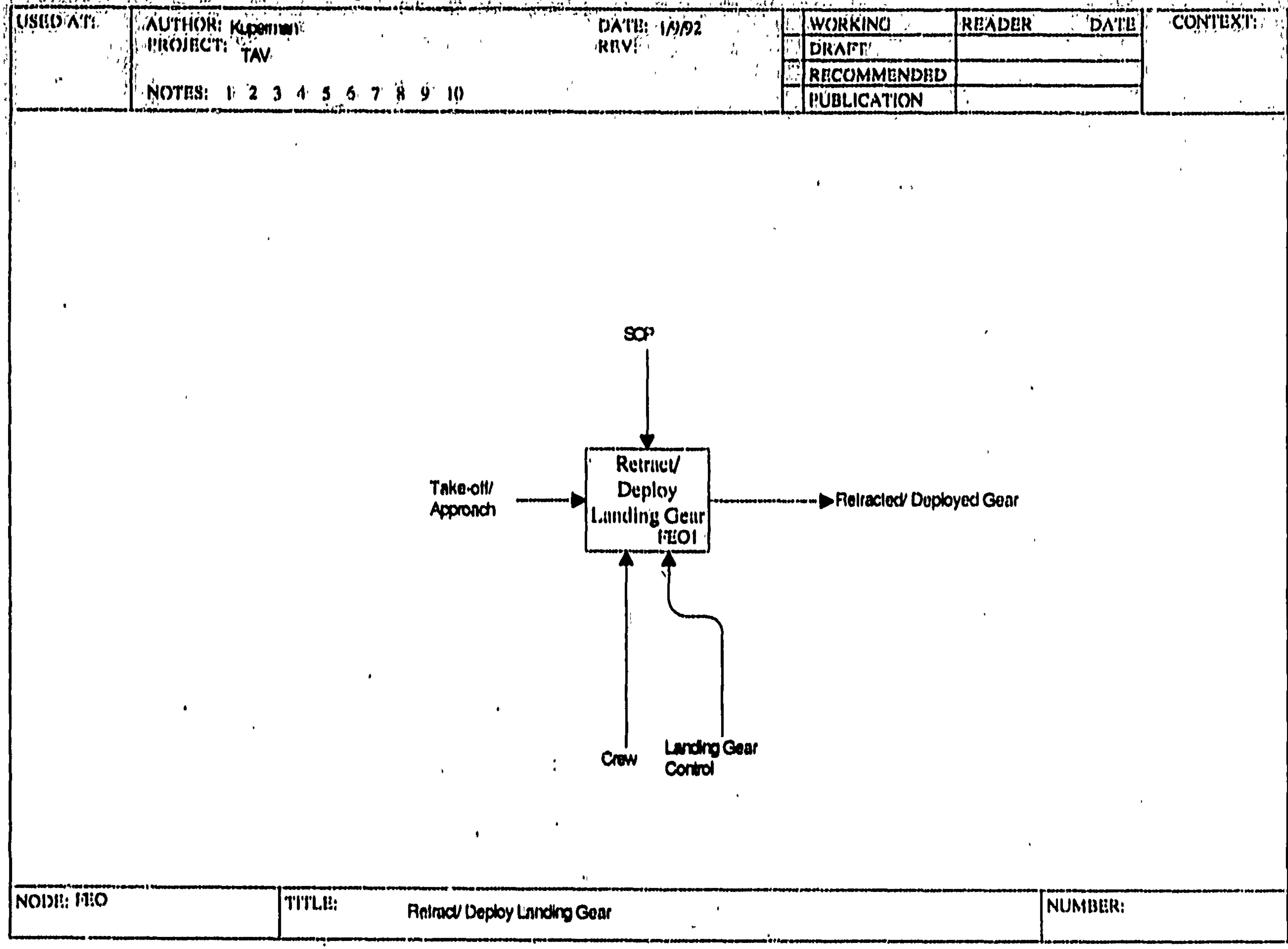

Figure 43. Retract/Deploy Landing Gear

TAV System Function: COMMUNICATE: TRANSMIT

The COMMUNICATIONS SUBSYSTEM is a highly automated link manager and communications processor which supports all incoming and outgoing message/data tasks. The crew interacts with the COMMUNICATIONS SUBSYSTEM through the COMMUNICATION MPD FORMAT screen. When the Mission Plan or a mission event requires the crew to transmit a message, the crew performs TAILOR MPDs to bring up this screen on one of the MPDs. This screen confirms that the COMMUNICATIONS SUBSYSTEM has established a valid link with the MILSTAR communications satellite constellation. Frequency selection, network entry, satellite "handshaking," channel allocation, and subscriber authentication are all automated and are performed by the COMMUNICATIONS SUBSYSTEM. The MILSTAR link is constantly maintained throughout the duration (Pre-Flight through Post-Flight) of the TAV mission.

The crew first selects the node with which to communicate. Possible nodes include Command and Control Center(s), Operations Center(s), and Component Command Center(s). The COMMUNICATIONS SUBSYSTEM presents a list of network subscribers and the crew employs the BEZEL BUTTONS to achieve connectivity (i. e., a digital plugboard). The crew then selects the type of message: (secure) voice, (encrypted) video (either "live" broadcast or previously recorded) or telemetry (either TAV or payload performance data), or other (encrypted) data (such as from an on-board scientfic experiment). The DATA BASE MANAGEMENT SUBSYSTEM advises the crew of messages/data available for transmission.

The crew performs the selection by using the BEZEL BUTTONS. The DATA BASE MANAGEMENT SUBSYSTEM will also automatically route the selected message(s) into a message queue maintained by the COMMUNICATIONS SUBSYSTEM. The screen is updated by the COMMUNICATIONS SUBSYSTEM to reflect that a message is ready for transmission (and to inform the crew as to message protection: in clear, secure/encrypted). The crew initiates message transmission by means of a single BEZEL BUTTON depression. (If [secure] voice is selected, the microphone, integrated into the crew's helmet, is employed and the Transmit/Receive control, integrated into the crewmembers' INTERCOMMUNICATIONS SUBSYSTEM connection, is used to regulate the direction of the voice traffic.) The message is transmitted. The COMMUNICATIONS SUBSYSTEM informs the crew as to the receipt of the transmission by the selected network subscriber(s).

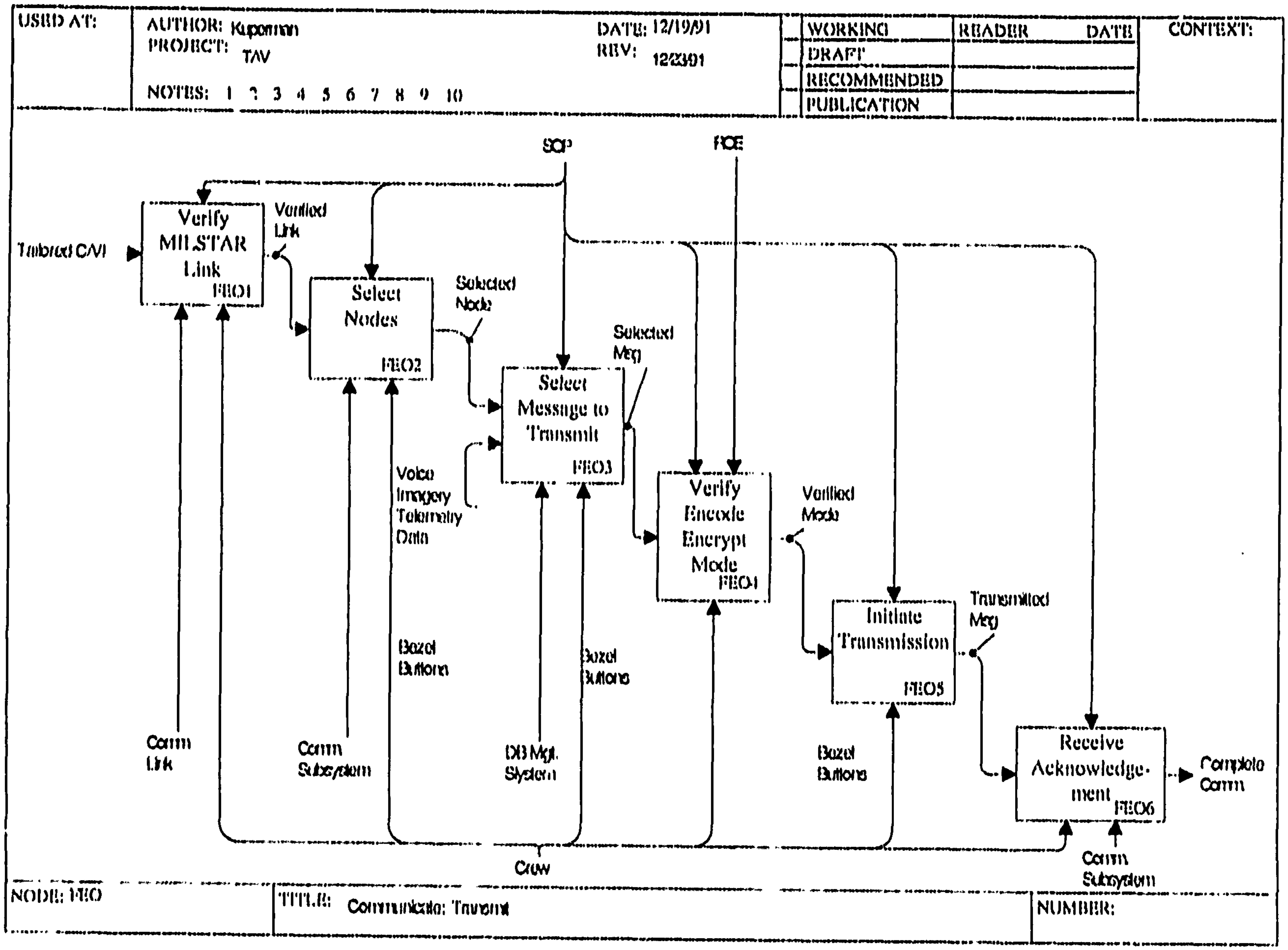

Figure 44. Communicate: Transmit

TAV System Function: MONITOR TRAJECTORY

Trajectory monitoring is performed frequently throughout the TAV mission. Beyond its obvious safety-of-flight implications, it is required (by SOP) to be accomplished during Take-Off, during Climbout/Descent (to assure that a constant dynamic pressure maneuver is being accomplished), and during any Trans-Orbital Maneuver.

TAILOR MPDS is performed to bring up the TRAJECTORY MANAGEMENT MPD FORMAT screen. (This format is a subsidiary of the FLIGHT CONTROL SUBSYSTEM MPD FORMAT and is reached by first bringing up that format and then selecting the subformat by means of the BEZEL BUTTONS.) The TRAJECTORY MANAGEMENT MPD FORMAT is used in conjunction with the flight control information presented on the VSD and HSD FLIGHT CONTROL SUBSYSTEM MPD FORMAT screens. It provides finer resolution in its display of trajectory information. The information is provided by the FLIGHT CONTROL SUBSYSTEM which includes a TRAJECTORY MANAGER (processor).

The TRAJECTORY MANAGER continuously computes and updates (mission abort) trajectories for the primary and two alternate recovery bases. This information supports safety-of-flight. Its primary role is the computation of the current flight path. For example, during Climbout, it will compute the trajectory required to reach the Ramjet/Scramjet transition point (in terms of altitude, Mach Number, and Latitude/Longitude). The actual function of Trajectory Management is automated and is executed by the FLIGHT CONTROL SUBSYSTEM. Flight Director commands are

generated by the FLIGHT CONTROL SUBSYSTEM, based on the current planned TAV trajectory (as generated by the TRAJECTORY MANAGER), and are displayed on the VSD to provide the crew with situational awareness information.

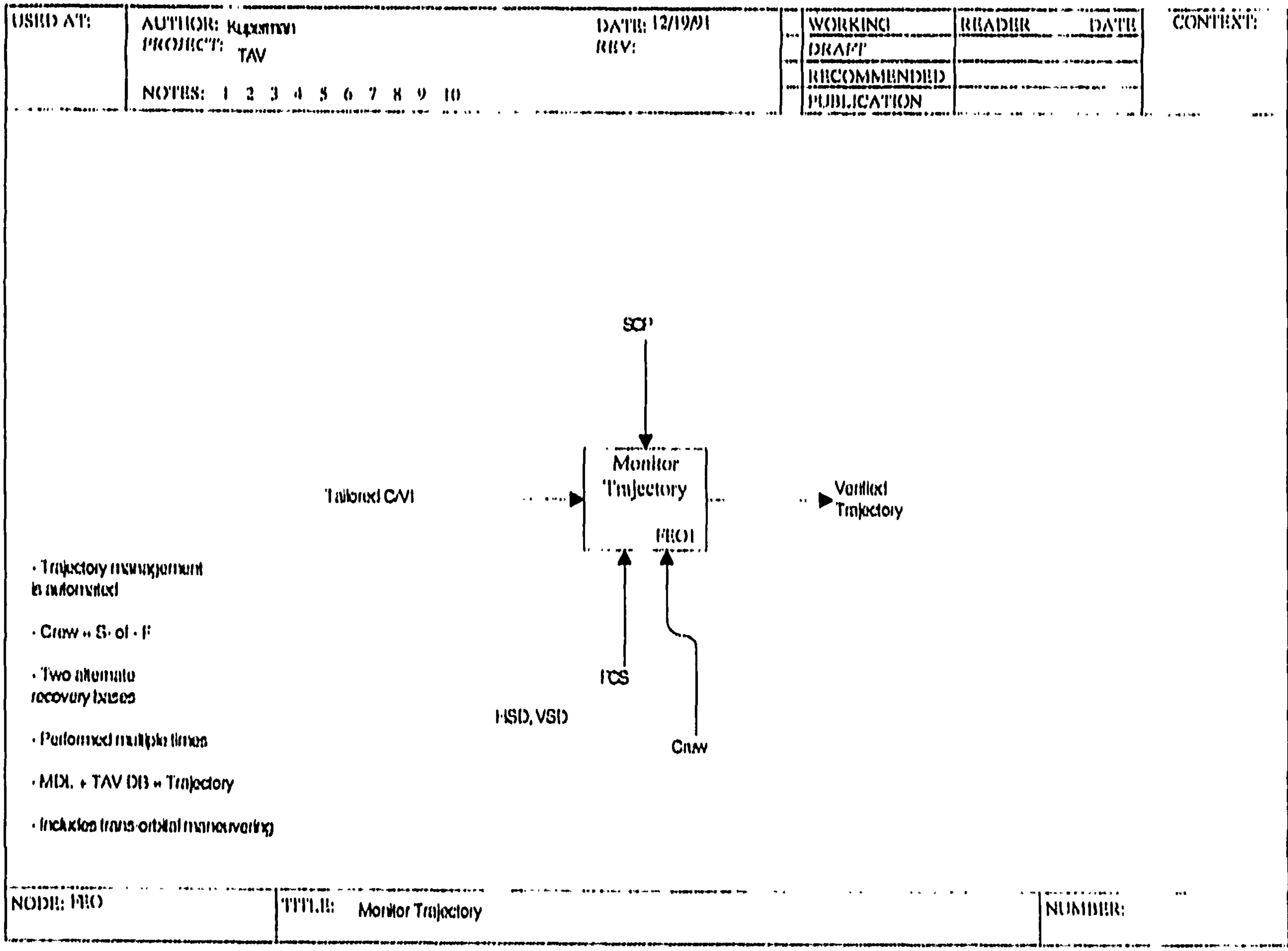

Figure 45. Monitor Trajectory

TAV System Function: STABILIZE TAV

Stabilization of the TAV may be required at any one of several points during the mission. Stabilization consists of accomplishing fine adjustments to TAV attitude and rates. It is assumed to be required as a predecessor to any trans-orbital maneuver, trajectory/orbital adjustment, or payload operation. The function is accomplished in conjunction with the TRAJECTORY MANAGEMENT capability of the FLIGHT CONTROL SUBSYSTEM, with GPS providing an external, supplementary reference.

The crewmember selects the Trajectory Management MPD Format screen, a secondary display format accessed from the Flight Control Subsystem MPD Format screen. Using the BEZEL BUTTONS, he applies fine control inputs. The crewmember monitors the changes to the TAV state vector (attitude, altitude, Mach Number, inclination, orbital eccentricity, ascension, etc.), together with their respective rates. Once the TAV has been stabilized within nominal parameters, the next mission event can be initiated.

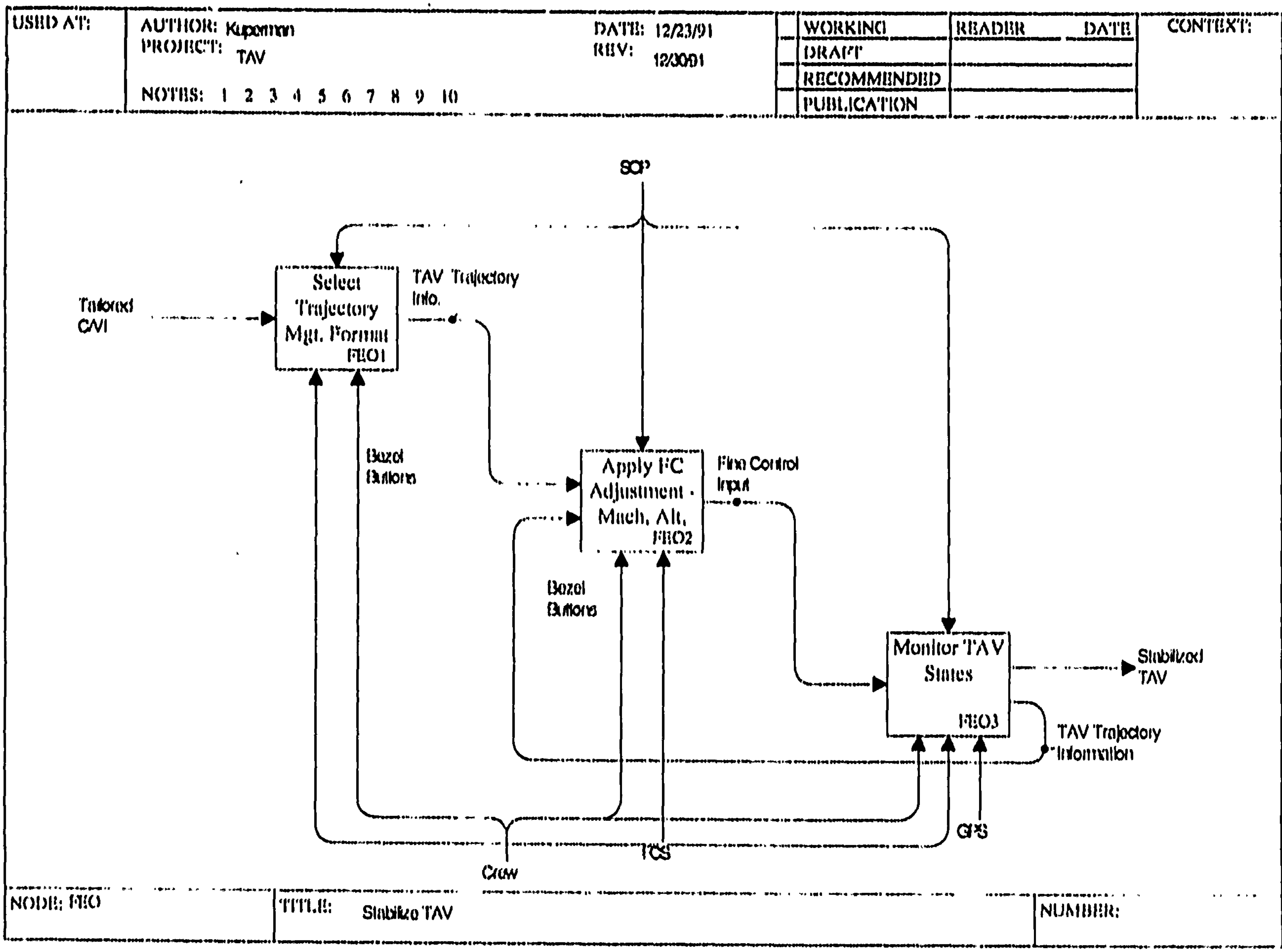

Figure 46. Stabilize TAV

TAV System Function: OPEN/CLOSE PAYLOAD BAY DOORS

A number of TAV operations will require the opening of the Payload Bay. These operations include: orbital/suborbital payload operation, payload ejection/deployment, space asset recovery/repair, space asset resupply, exchange of personnel, and the operation of certain experiment packages.

Payload Bay door operations are not normally automated. A positive crew control input is deemed to be required to change the state of the doors.

The C/VI is assumed to be tailored for this function. The Payload Bay Subsystem MPD Format screen appears on at least one display surface. The crewmember verifies the current state of the bay doors (partially/fully opened or closed). The BEZEL BUTTONS are used in changing this state. The crewmember verifies the changed state.

The PAYLOAD BAY SUBSYSTEM also supports the crew in monitoring the environment within the Payload Bay itself. Depending on mission and/or payload requirements, this environment may range between "Earth-normal" and exoatmospheric.

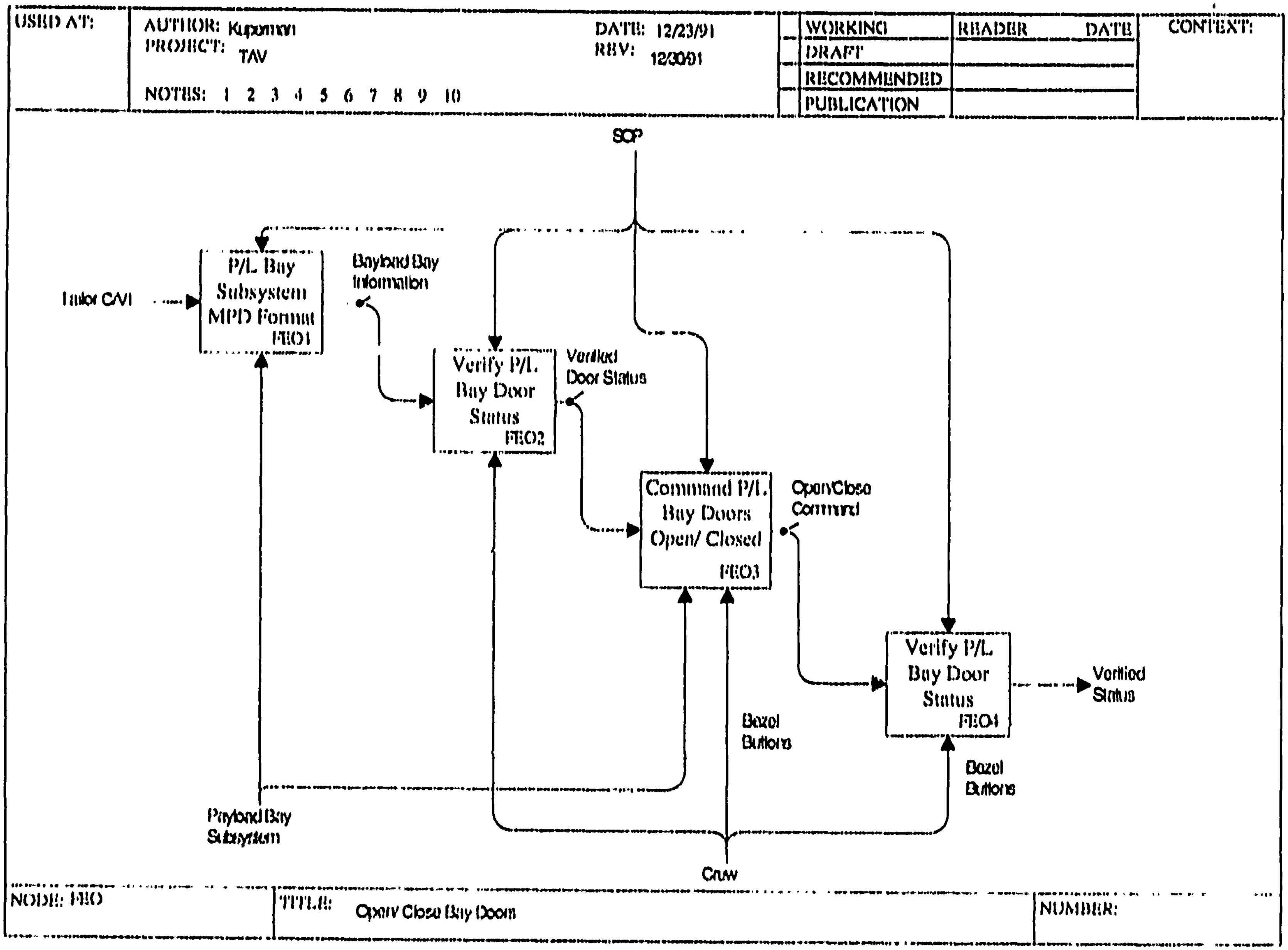

Figure 47. Open/Close Bay Doors

TAV System Function: OPERATE PAYLOAD

The crew notes the approach of a mission event which requires payload operation. (This information is integrated into the situational awareness displays, primarily the HSD.) The Payload Bay Subsystem MPD Format screen provides the crew with information concerning and operational control over the payload bay doors. The crew uses this information to verify that the doors are fully opened. The Payload Interface Operation MPD Format screen, a secondary screen to the Payload Interface Subsystem MPD Format screen, is activated by BEZEL BUTTON. When activated, the new screen provides the crew with direct (manual) operational control over the payload modes and states.

Normally, all payload operations are automated. The MDL includes payload moding, state change, and other operationally required data. These data are provided to the PAYLOAD INTERFACE SUBSYSTEM by the DATA MANAGEMENT SUBSYSTEM.

The crew verifies that the required (by the Mission Plan) payload state and moding have been accomplished. (If not, they accomplish these requirements by employing the BEZEL BUTTONS to manually change them.) Payload operations (e. g., surveillance and imagery recording) then take place according to the Mission Plan. When payload operations have been completed, the crew verifies the full closure of the payload bay doors (on the Payload Bay Subsystem MPD Format screen).

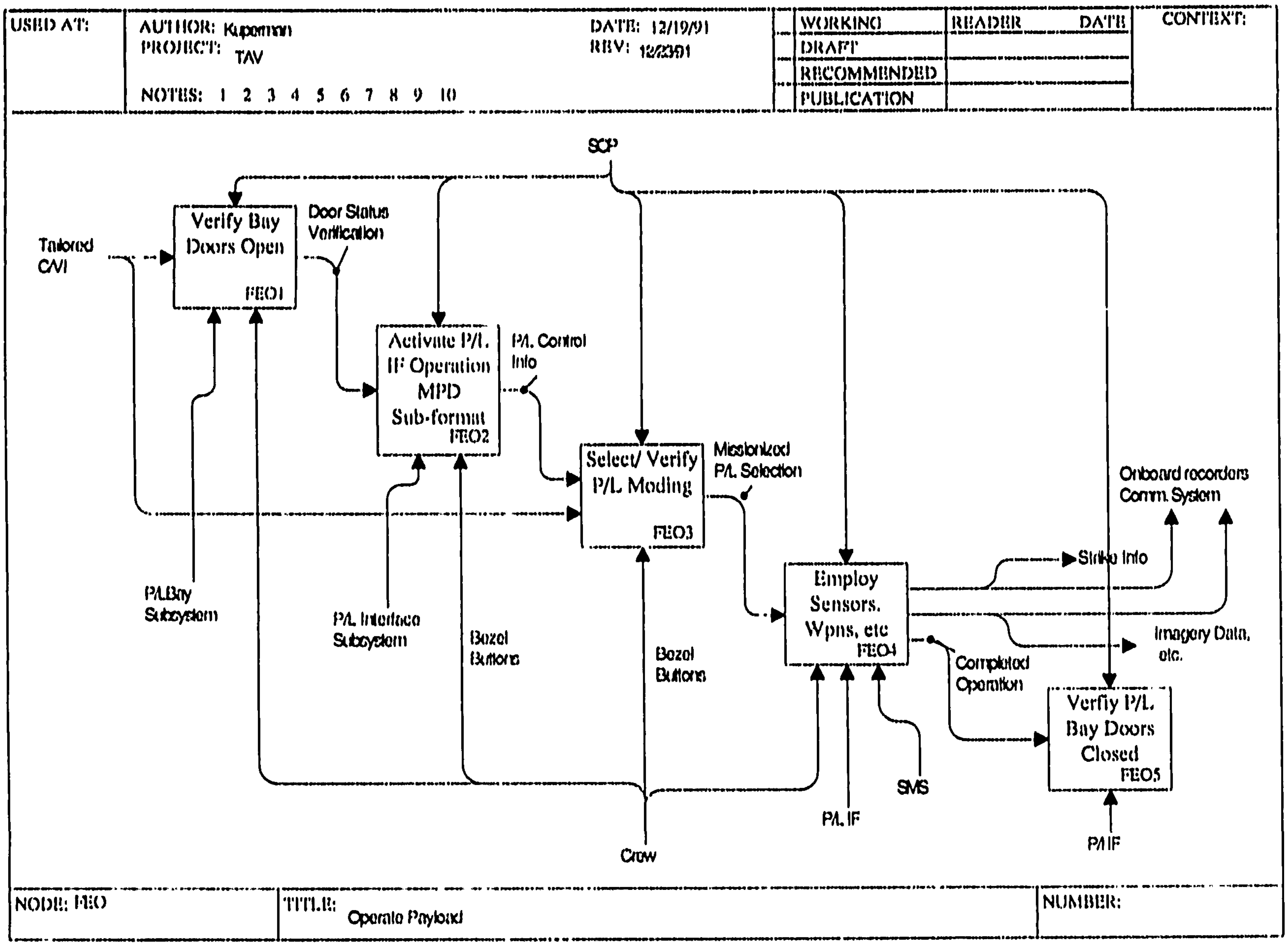

Figure 48. Operate Payload

TAV System Function: DEPLOY PAYLOAD

The crew notes the approach of a mission event which requires payload deployment. (This information is integrated into the situational awareness displays, primarily the HSD.) The Payload Bay Subsystem MPD Format screen provides the crew with information concerning and operational control over the payload bay doors. The crew uses this information to verify that the doors are fully opened. The Payload Interface Operation MPD Format screen, a secondary screen to the Payload Interface Subsystem MPD Format screen, is activated by BEZEL BUTTON. When activated, the new screen provides the crew with direct (manual) operational control over the payload ejection/boost initiation capabilities of the PAYLOAD INTERFACE SUBSYSTEM.

Normally, all payload operations are automated. The MDL includes payload eject/boost information (times, inclinations, etc.), and other operationally required data. These data are provided to the PAYLOAD INTERFACE SUBSYSTEM by the DATA MANAGEMENT SUBSYSTEM.

The crew activates (BEZEL BUTTONS) the Payload Interface Eject/Boost MPD Format screen, a secondary screen to the Payload Interface Subsystem MPD Format screen. Payload operations (e. g., ejection or boosting of a payload into a predetermined orbit) are normally automated functions which take place according to the Mission Plan. The PAYLOAD INTERFACE SUBSYSTEM performs the actual action. When the payload deployment operation has been completed, the PAYLOAD INTERFACE SUBSYSTEM generates a "Payload

Deployed" notification message on the MPD screen. The crew verifies that deployment has actually occurred by means of a closed-circuit television system which monitors the Payload Bay. The crew then verifies the full closure of the payload bay doors (on the Payload Bay Subsystem MPD Format screen).

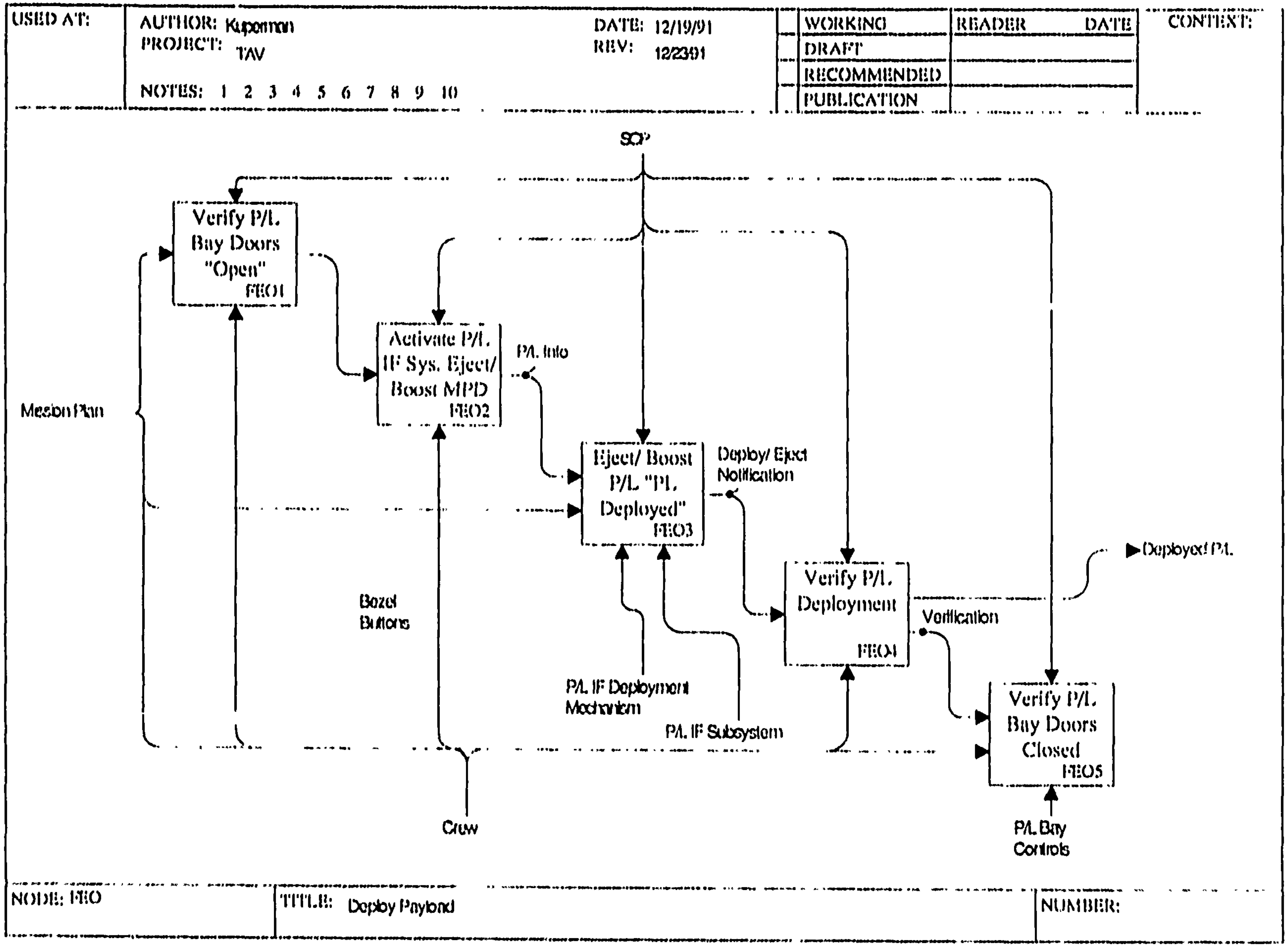

Figure 49. Deploy Payload

TAV System Function: RECORD PAYLOAD DATA

Payload operation or spaceborne scientific and commercial experimental packages may produce technical data and/or imagery. In addition, the operation of the payload/package may require monitoring of states/modes for engineering purposes. These data may either be transmitted in real-time (See TAV System Function: COMMUNICATE: TRANSMIT) or recorded on-board the TAV for subsequent transmission and/or retrieval.

The on-board data/imagery recorders are a capability of the DATA MANAGEMENT SUBSYSTEM. It is assumed that assignment and activation of recorders and pairing of specific data sources to recorders/recorder channels is automated and under the control of the DATA MANAGEMENT SUBSYSTEM. It is further assumed the the MDL contains all information (e. g., start/stop times, data types, recorder channel assignments, etc.) required to accomplish the automated data recording function.

The crewmember observes upcoming mission plan requirements for on-board data recording on the HSD and/or on the Payload Interface Subsystem, Payload Operations MPD Format screen. He activates the Data Management Subsystem, Data Recording (secondary) MPD Format screen and observes the "Ready" state of the assigned recorders/channels. When data are passed from the payload/experiment across the PAYLOAD INTERFACE SUBSYSTEM to the DATA MANAGEMENT SUBSYSTEM, he observes the recorder state transition to "Recording" and verifies that data recording is taking place. At the completion of the data recording episode,

the crewmember observes the recorder(s) state transition to "Off."

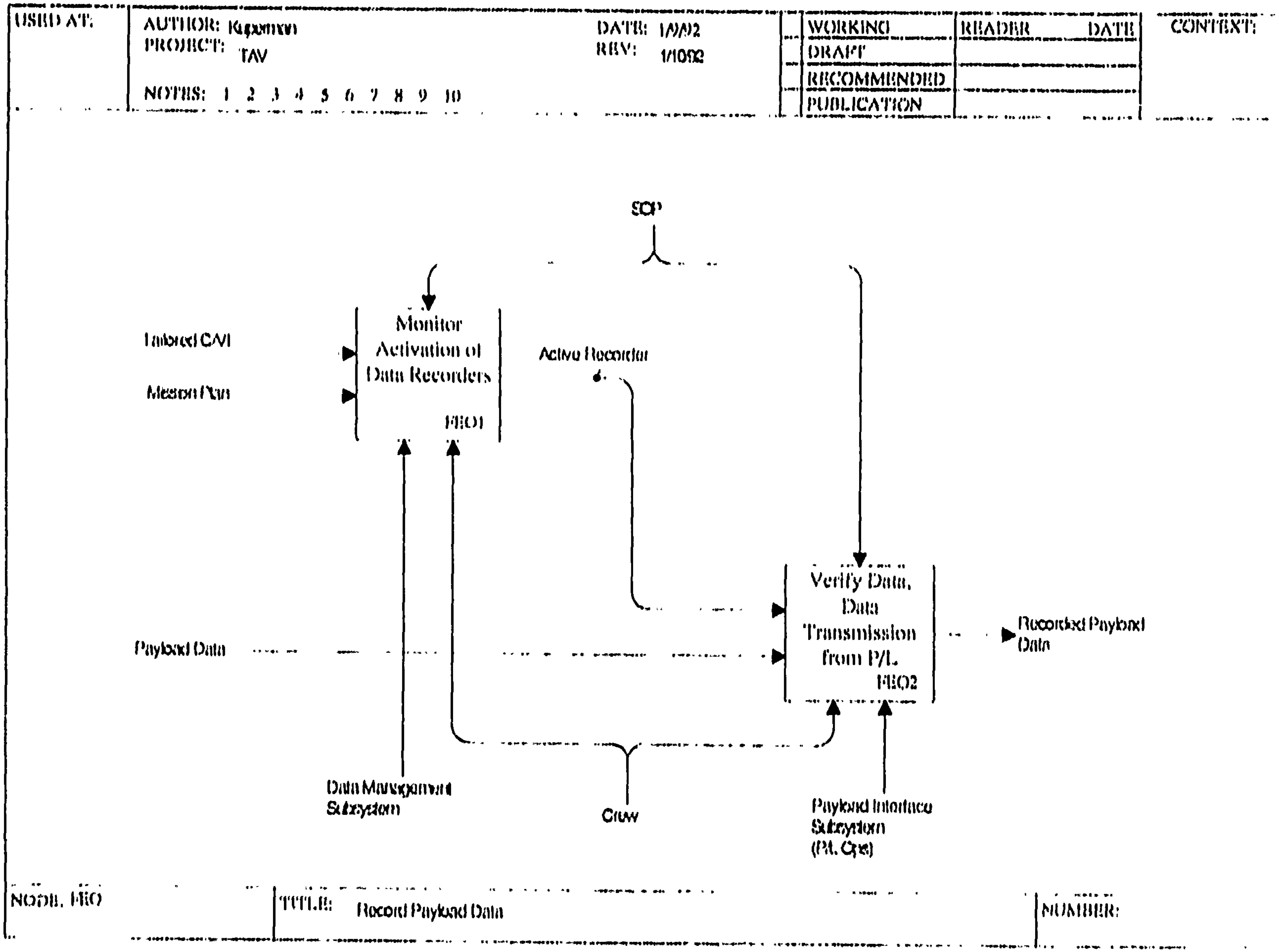

Figure 50. Record Payload Data

TAV System Function: PERFORM ENGINE RESTART

Engines are shut down during the On-Orbit phase of the TAV mission. In order to initiate the De-Orbit phase, at the conclusion of On-Orbit operations, the crew must restart the rocket engines.

At the mission plan time for rocket engine restart, as reflected on the HSD, the crewmember employs an engine restart switch integrated into the split throttle flight control. He observes the successful refiring of the rocket engines on the Engine Management Subsystem MPD Format screen.

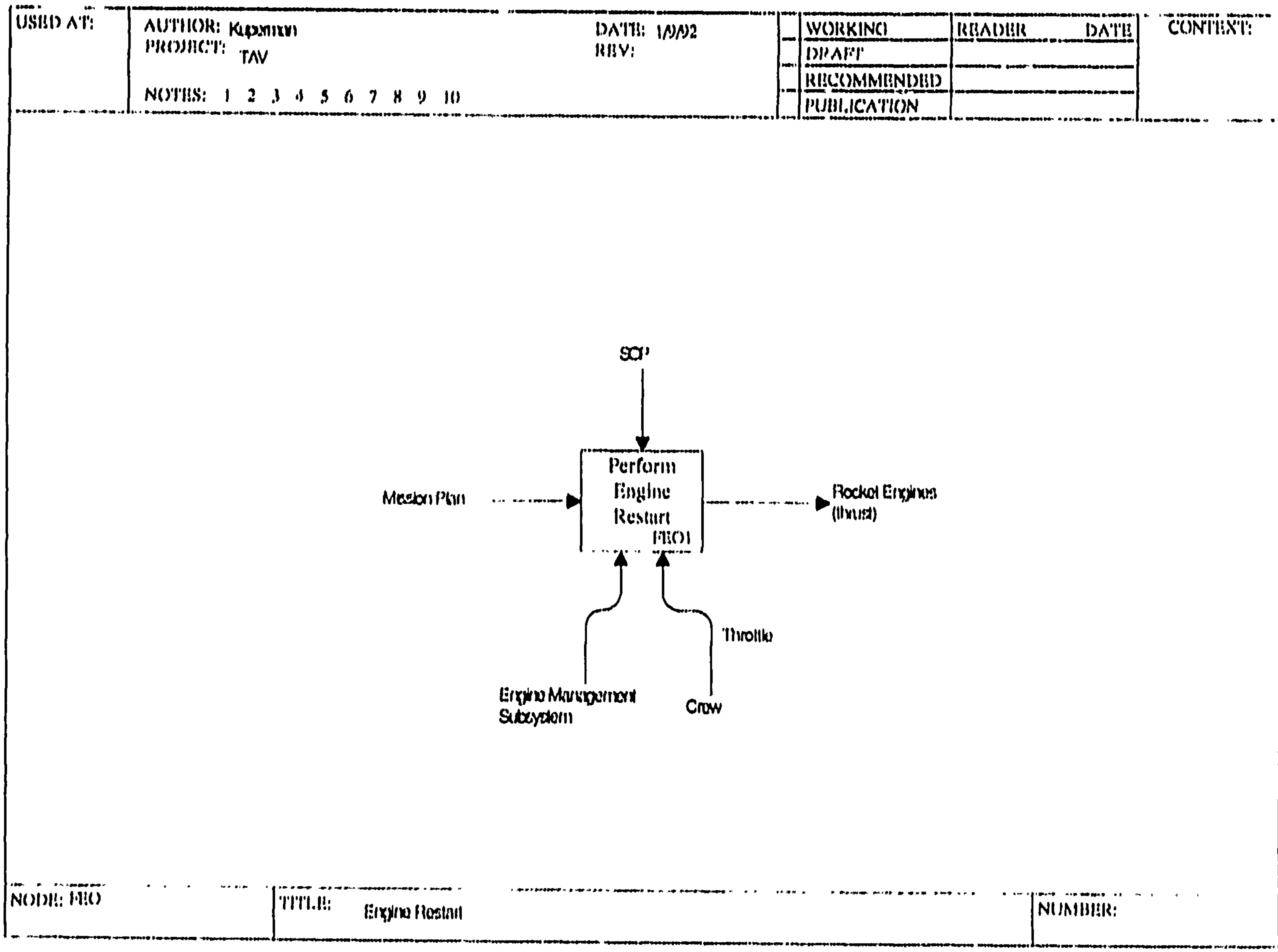

Figure 51. Perform Engine Restart

TAV System Function: ADJUST TRAJECTORY (MANUAL)

The System Function is a manual backup or override capability provided to support Safety-of-Flight contingencies. In the event of an inflight mission abort declaration, the crew would employ this capability to either 1) assume manual control over the TAV trajectory (i. e., "hand fly" the vehicle) or, in accordance with Tactical Doctrine, 2) to select either the primary recovery base or one of the two alternate recovery bases (for which the TRAJECTORY MANAGER of the FLIGHT CONTROL SUBSYSTEM continuously replans recovery trajectories). The latter case is similar to the "Fly to Destination" capability of a modern aircraft mission-following, automated navigation subsystem.

It is assumed that (at least) one crewmember, "the pilot flying," always has the Flight Control Subsystem MPD Format screen as an active display. It is also again assumed that the actual flight control functions are automated, with the stick and throttle serving to afford a safety-of-flight backup capability.

Overriding the automated FLIGHT CONTROL SUBSYSTEM-generated trajectory control function is accomplished by activating the MANUAL OVERRIDE function on the MPD (BEZEL BUTTON), followed by the input of a positive control movement to either the stick or throttle. The automated flight control system disengages and the crewmember has manual flight control authority. The crewmember can either proceed with the mission (using the Flight Director commands on the VSD as a primary reference) or select (BEZEL BUTTONS) one of the preplanned recovery bases, if the situation

warrants mission aborts. Once a "within nominal" trajectory has been established, the crewmember can either continue manual flight control, or re-engage the automated FLIGHT CONTROL SUBSYSTEM.

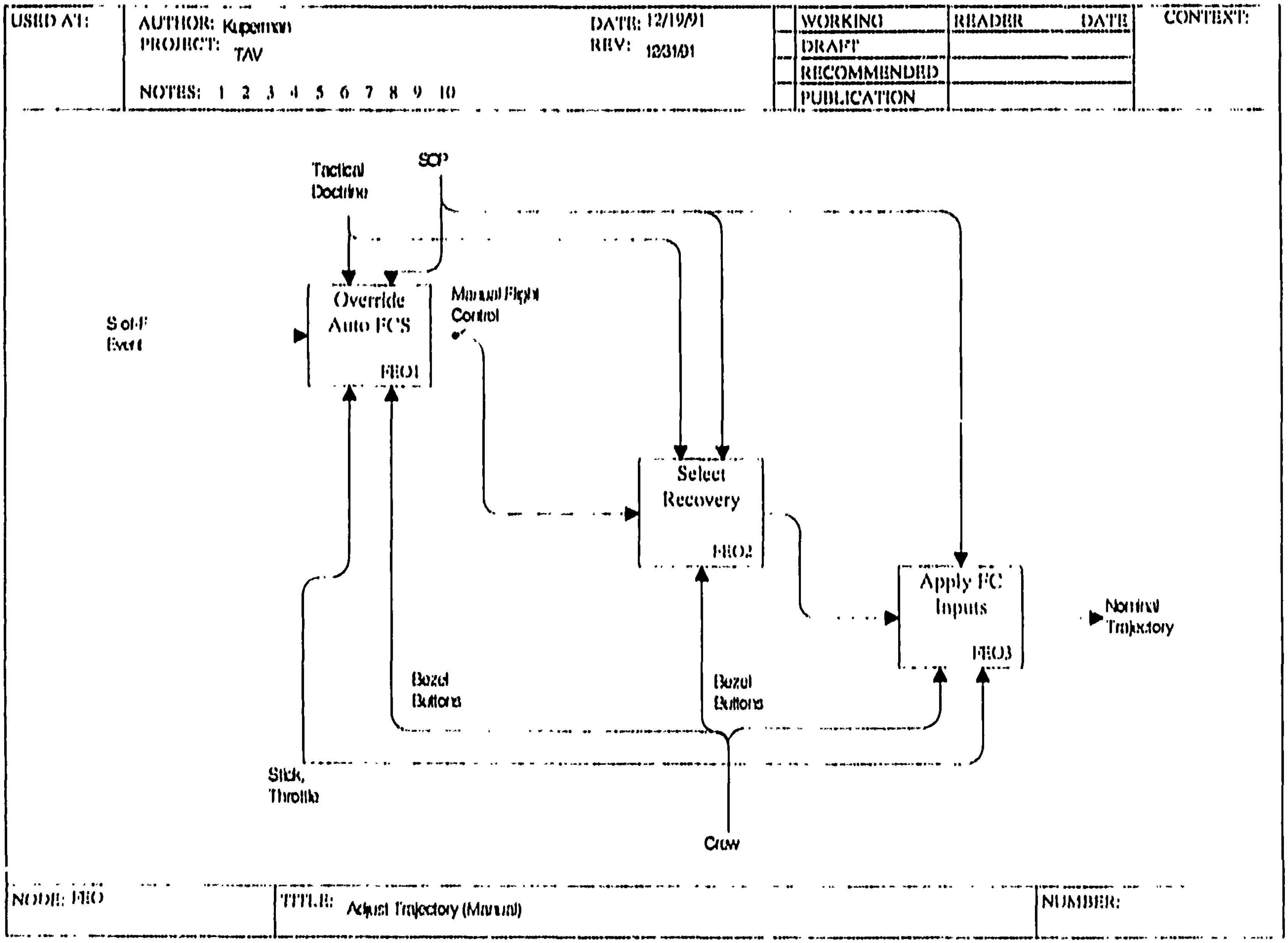

Figure 52. Adjust Trajectory (Manual)

TAV System Function: COMMUNICATE: RECEIVE

An external network subscriber transmits a message to the TAV at some point during the mission. The Communications Processor function of the COMMUNICATIONS SUBSYSTEM receives the incoming message and performs any required authentication or verification. The successful receipt of the transmitted message is automatically acknowledged to the sending node. The message is automatically parsed by the COMMUNICATIONS SUBSYSTEM and an advisory is generated for the crew. The advisory, displayed on one or more of the MPDs, contains a message identification field (assigned by the COMMUNICATIONS SUBSYSTEM), a subscriber identification field, and a message priority field. The crew responds to the advisory by using the BEZEL BUTTONS to bring up the COMMUNICATION MPD FORMAT screen on one of the MPDs. The crew uses the BEZEL BUTTONS to select the specific message to be reviewed from a prioritized received message queue (maintained by the COMMUNICATIONS SUBSYSTEM). The full text of the message then appears on the MPD. (The COMMUNICATIONS SUBSYSTEM automatically decrypts incoming messages.) The crew reviews the message content. If the message requires a modification of the Mission Plan, for example, the crew employs the BEZEL BUTTONS to actively consent to this action. Upon receiving crew consent, the COMMUNICATIONS SUBSYSTEM will automatically pass the relevant portion(s) of the message to the DATA BASE MANAGEMENT SUBSYSTEM which will automatically update the appropriate on-board data bases. The crew will monitor the impact of this update (e. g.,

on the HSD, VSD, and/or the PAYLOAD INTERFACE SUBSYSTEM MPD FORMAT screens) as the mission progresses.

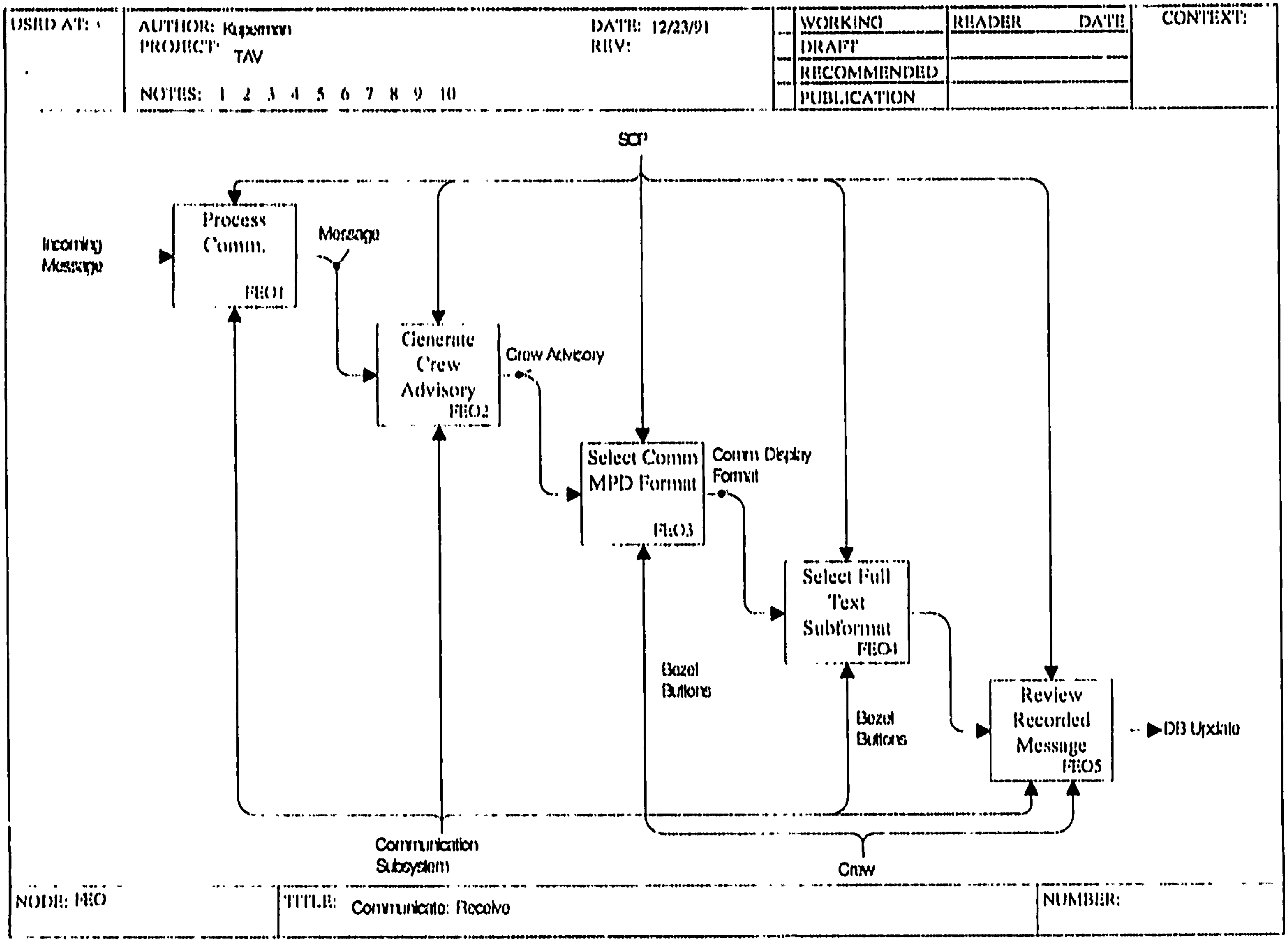

Figure 53. Communicate: Receive

TAV System Function: UPDATE MISSION PLAN

With the possible exception of communications blackouts which may be experienced during the Climbout and Descent phases of the MES, the TAV remains in direct, two-way communication (by means of MILSTAR) with both the Mission Operations Center and the Command and Control Center. Should developing events warrant it, either Center can prepare and transmit updates to the MDL. For example, additional trans-orbital maneuvering may be commanded (in order to avoid crossing certain geopolitical boundaries) or additional on-orbit operations of TAV payload capabilities may be required. These updates, in the form of changes to the Mission Plan portion of the MDL, are passed to the TAV as a special case of the COMMUNICATE: RECEIVE TAV System Function.

Upon generation of a MDL Update Message alert (FE01), the crewmember employs the control functions (BEZEL BUTTONS) associated with the Communications Subsystem MPD Format screen (FE02) to acknowledge receipt. He next tailors the C/VI to bring up the Data Management Subsystem MPD Format screen (FE03) on one of his displays. The screen shows that the COMMUNICATIONS SUBSYSTEM has queued an Update Message for the DATA MANAGEMENT SUBSYSTEM to act on. He views the updated Mission Plan data and anticipates its effect on TAV operations and crew mission pacing. A positive control action (BEZEL BUTTON) is executed to pass the replanning data to the DATA MANAGEMENT SUBSYSTEM (FE04). Once the crewmember provides this input, the DATA MANAGEMENT SUBSYSTEM automatically updates the Mission Plan portion of the MDL. The

crewmember verifies that the MDL update has been accepted (FE05). (These crew actions are similar to the function of LOAD/VERIFY MDL which is performed during the Pre-Flight phase of the mission.)

Subsequently, the crewmember observes the results of the update to the Mission Plan as the revised TAV trajectory/operations schedules are executed by the FLIGHT CONTROL, NAVIGATION, STORES MANAGEMENT, PAYLOAD INTERFACE, and possibly other of the TAV SUBSYSTEMS during the course of the mission.

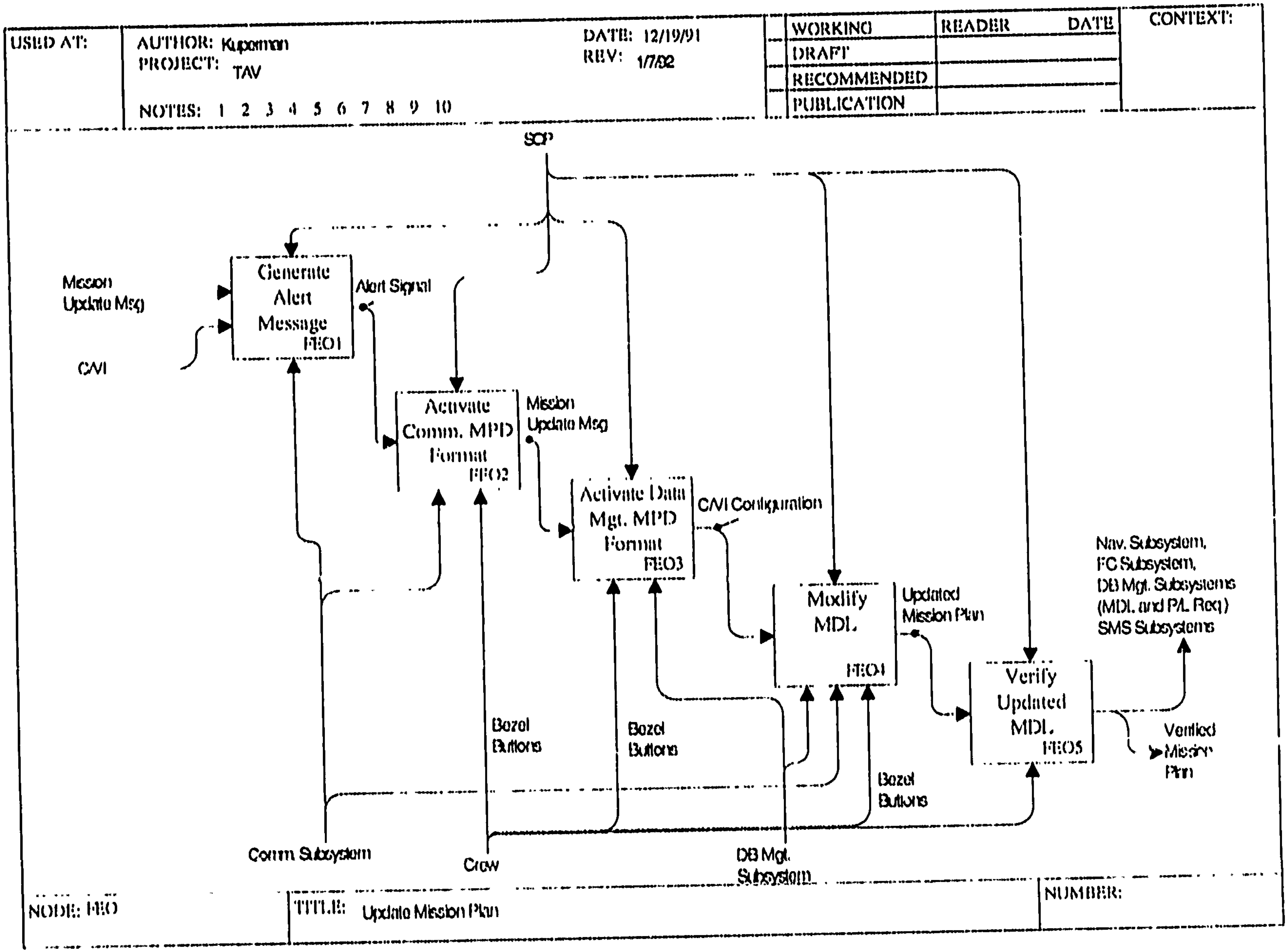

Figure 54. Update Mission Plan

TAV System Function: UPDATE PAYLOAD GUIDANCE AND CONTROL

With the possible exception of communications blackouts which may be experienced during the Climbout and Descent phases of the MES, the TAV remains in direct, two-way communication (by means of MILSTAR) with both the Mission Operations Center and the Command and Control Center. Should developing events warrant it, either Center can prepare and transmit updates to the MDL. For example, the time-on-target may change or, in the case of a surveillance mission, the sensor operating modes may be replanned. These updates, in the form of changes to the guidance and control portions of the MDL, are passed to the TAV as a special case of the COMMUNICATE: RECEIVE TAV System Function.

The crewmember employs the control functions (BEZEL BUTTONS) associated with the Communications Subsystem MPD Format screen to acknowledge the receipt of a MDL Update Message. He next tailors the C/VI to bring up the Data Management Subsystem MPD Format screen on one of his displays. The screen shows that the COMMUNICATIONS SUBSYSTEM has placed an Update Message in the "update waiting" queue of the DATA MANAGEMENT SUBSYSTEM. He views the updated guidance and control data and anticipates its effect on the Mission Plan. (This is similar to the function of LOAD/VERIFY MDL which is performed during the Pre-Flight phase of the mission.) A positive control action (BEZEL BUTTON) is executed to pass the update to the DATA MANAGEMENT SUBSYSTEM. Once the crewmember provides this input, the DATA MANAGEMENT SUBSYSTEM automatically updates the Payload Operations portion of

the MDL. Subsequently, the crewmember observes the accomplishment of the update to the Mission Plan as the revised guidance and control schedule is carried out by the PAYLOAD INTERFACE SUBSYSTEM during Payload Operations.

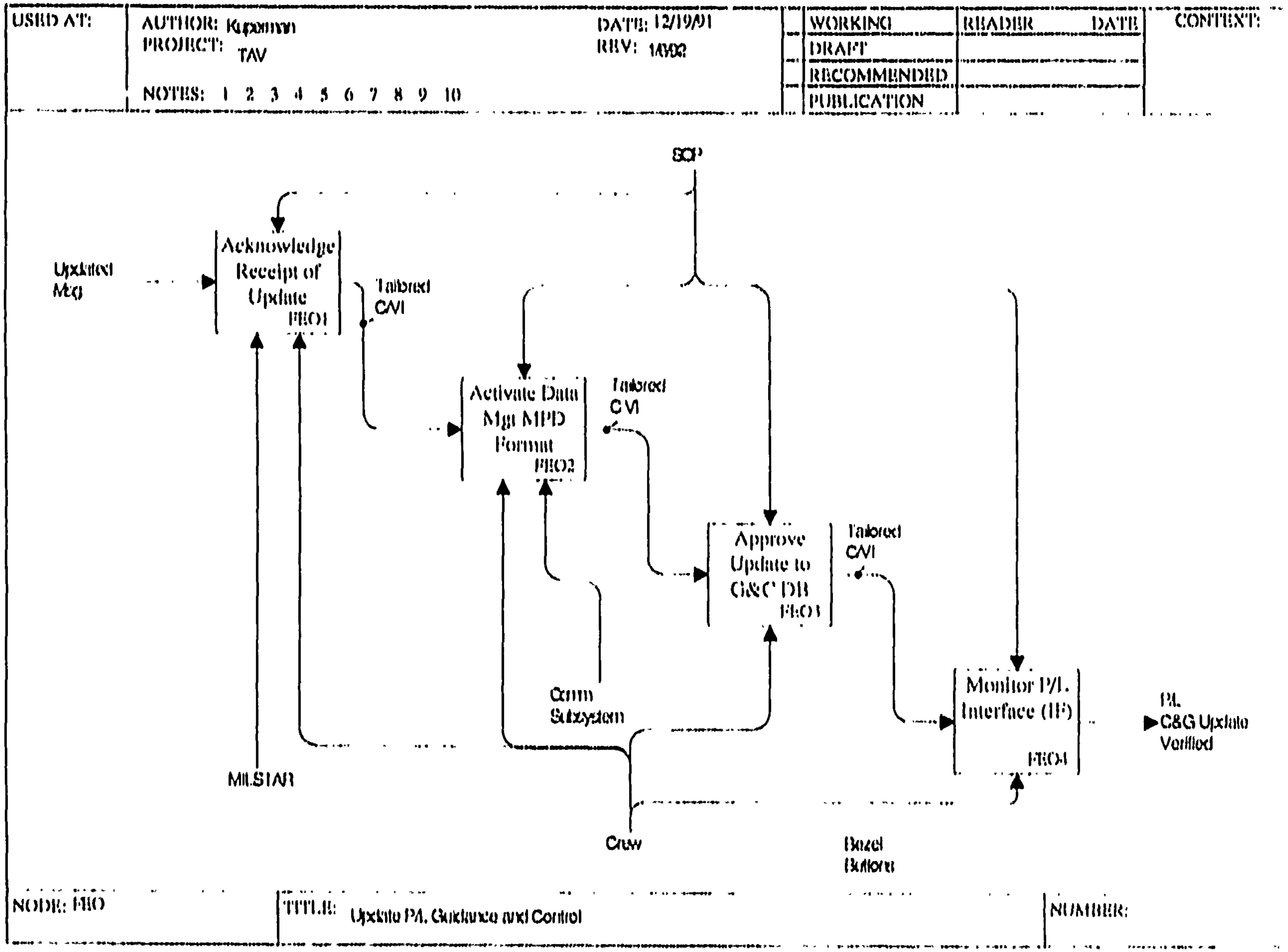

Figure 55. Update P/L Guidance and Control

TAV System Function: RESPOND TO WCA

The TAV is assumed to employ a sophisticated subsystem status monitoring capability, the "SELF-HELP" SUBSYSTEM. One of the functions of this subsystem is to generate Warning, Caution, and Advisory (WCA) alerts to the aircrew. WCA alerts (both auditory and visual annunciations) are based on the results of subsystem status monitoring capabilities and on the results of "Built-in Test" functions, commanded by the "SELF-HELP" SUBSYSTEM on other TAV subsystems. Auditory alerts are received over the INTERCOMMUNICATIONS SUBSYSTEM (headphones) while visual alerts appear on the MPD format screens. WCA alerts are prioritized with Warnings representing the most severe condition (e. g., an actual or imminent subsystem failure) and Advisories representing the least severe condition (e. g., a non-life threatening crew compartment lighting fluctuation). Events which lead to the generation of Warning alerts generally will affect the TAV's capability to perform the mission while Caution and Advisory conditions generally do not have (immediate) impact on mission effectiveness. Following this logic, the IDEF0 depictions reflect that the crew must acknowledge Warning or Caution annunciations (but not Advisories).

The "SELF-HELP" SUBSYSTEM is also assumed to support the crew in diagnosing subsystem problems, in performing "trouble-shooting" operations to restore/recover failed/failing subsystem capabilities, and in reconfiguring subsystems or subsystem capabilities in order to regain an operationally capable vehicle.

The crew support functions are identified in the IDEF0 depiction of this TAV System Function.

In the case of a Warning or Caution alert, the crew must acknowledge the visual and auditory annunciation. This is done by means of the BEZEL BUTTONS at any of the station's MPDs. If the annunciation came as a result of a Caution (or Advisory) condition, the crewmember may elect to activate the "Self-Help" Subsystem MPD Format screen in order to obtain more specific information regarding the subsystem(s) involved; in the case of responding to a Warning annunciation, the "Self-Help" Subsystem MPD Format Screen is automatically generated upon crew response to the annunciation.

It is assumed that Warning and Caution annunciations are both visual and auditory, while Advisories are visual cue only. Acknowledgement will extinguish the highest level of annunciation. That is the auditory cue will be eliminated and the visual will be reduced in conspicuity (e. g., go from a blinking to a steady cue). It is assumed that the visual annunciation will be color coded with red reserved for Warning conditions, orange for Cautions, and yellow for Advisories.

The crewmember will inspect the "Self-Help" Subsystem MPD Format screen to obtain subsystem status information and to identify the specific out-of-nominal condition(s) which elicited the WCA annunciation. Automated subsystem testing can be employed through the "SELF-HELP" SUBSYSTEM in order to further diagnose the problem(s). If necessary, the "SELF-HELP" SUBSYSTEM

can assist the crewmember in accomplishing troubleshooting procedures to attempt to correct the problem. If this last step is not completely successful, the capabilities of the "SELF-HELP" SUBSYSTEM can be employed to assist in reassigning functions or capabilities across remaining "healthy" TAV subsystems. For example, if a failure in the COMMUNICATIONS SUBSYSTEM link to the GPS Satellite system results in loss of the TAV's primary navigation reference. The crew could elect to adopt the TAV's organic INS capability as the primary reference of the NAVIGATION SUBSYSTEM and to continue the mission under this degraded mode of operational capability.

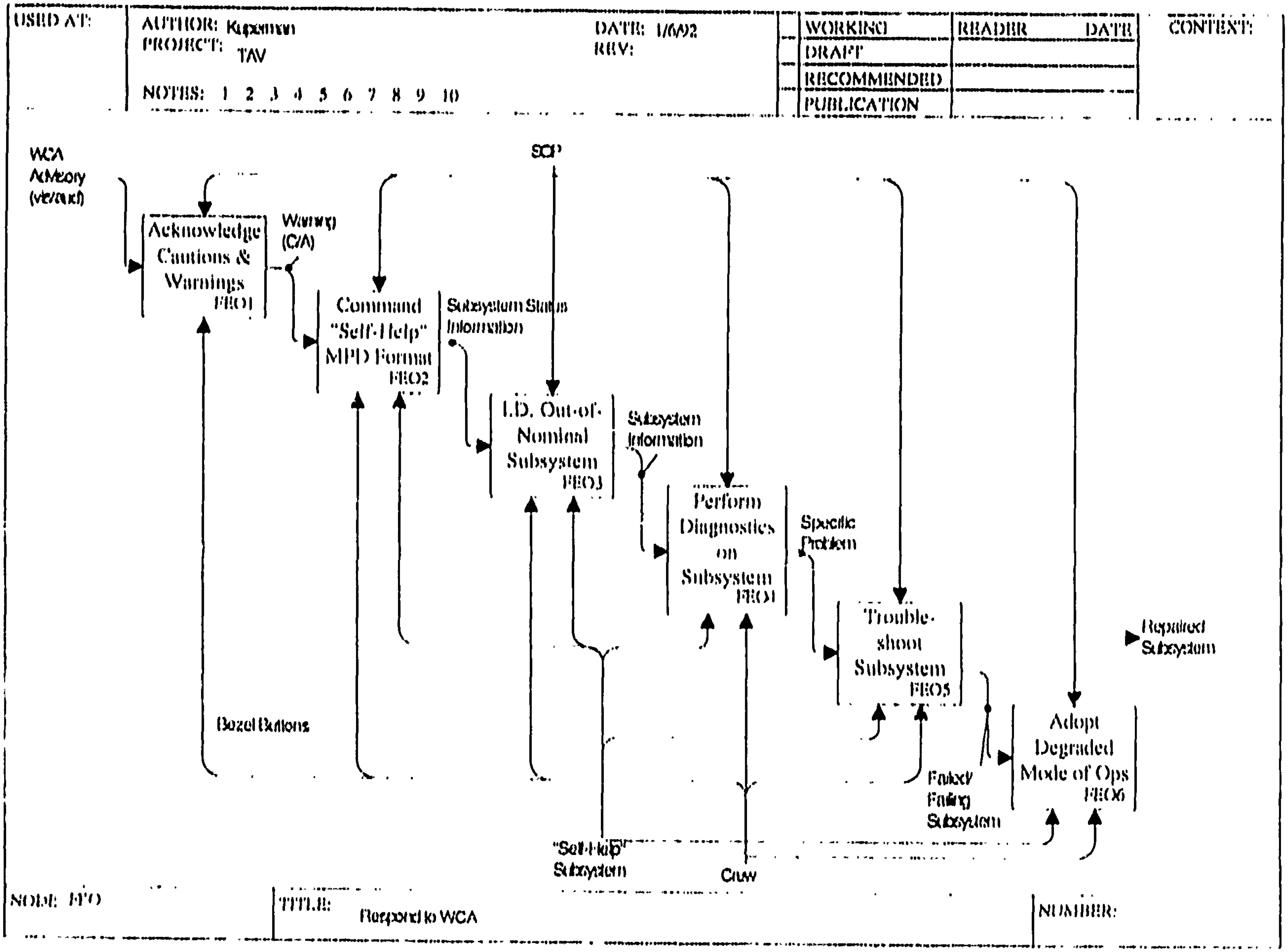

Figure 56. Respond to WCA

SECTION V

MEASURES OF EFFECTIVENESS AND PERFORMANCE

MEASURES

Measures of effectiveness (MOEs) are defined as system level descriptors while measures of performance (MOPs) are defined at the subsystem level. MOEs are selected to quantify the salient system attributes and reflect the mission area requirements supported by the system. MOEs may include both economic and non-economic (i. e., capability) factors. MOEs appropriate to the TAV system concept might include: life cycle costs, cost/pound of payload into orbit, cost/flight, lift capability, percent of missions projected to be performed successfully, turnaround time, probability of mission-available vehicle, etc.

MOPs are derived from MOEs by a decomposition process. Many MOEs will be common across mission types. Many MOPs may be mission specific. As was mentioned, MOEs are based on system-level attributes. These are identified below. MOPs, defined at the subsystem level, are derived from the IDEF0 representations (presented in Section IV) of the TAV System Functions. MOPs are documented in the form of Performance Criteria Specifications which correspond to each IDEF0 chart and which are also presented below.

MEASURES OF EFFECTIVENESS

To a great extent, the MOEs reflect the capability of the TAV system concept to satisfy high-level mission requirements.

The mission requirements are identified below and TAV system attributes are identified which support requirement satisfaction. It should be noted in the discussion that several of the TAV system capabilities support multiple MOEs.

Assured Access to Space: The United States space policy calls for establishing and maintaining a continuing capability to perform space missions. The TAV system concept helps to achieve an assured access to space capability because of several inherent attributes. Aircraft-like on-board avionics and ground support operations provide a high degree of individual vehicle reliablity, resulting in increased TAV availability and robust mission operations. TAV orbital flexibility, achieved by both takeoff inclination selection and trans-orbital maneuvering, results in greatly expanded "launch windows," avoiding potential delays. The TAV can perform takeoff, climbout, approach, and landing under night and adverse weather conditions, again enhancing access to space. Conventional runway basing obviates reliance on specialized launch and launch support facilities. Rapid TAV turnaround, provided by aircraft-like avionics, on-board subsystem malfunction diagnostics and troubleshooting support, prepared (containerized) payloads, and horizontal payload processing and insertion, greatly reduce the time between missions for each vehicle. The TAV's ability to perform "self-ferry," i. e., to fly from a recovery base to a second operating base, also supports reduced turnaround time. Additionaily, the TAV fleet will be capable of responding to surge tasking,

supporting the accomplishment of multiple space missions simultaneously.

<u>Global Range</u>: The hypersonic cruise and orbital operations capabilities of the TAV system are compatible with a global operating range. The capability to perform trans-orbital maneuvers places any point of the globe within the TAV's operational "footprint."

<u>Responsive Launch Capability</u>: Prepared, containerized payloads, wherein each payload type might support distinct mission requirements, together with horizontal payload processing, which greatly expedites payload readiness and payload/TAV mating, provide a highly responsive mission launch capability.

<u>Airplane-like Operations</u>: The TAV performs horizontal takeoffs and landings from conventional runways. Inter-mission turnaround is rapidly accomplished with a minimum of ground support. The vehicle itself is fully reusable, greatly reducing operating costs and turnaround times and complexity.

<u>Flexibility</u>: The capability of executing all-azimuth flight tracks, supported by horizontal take-off from conventional runways and trans-orbital maneuvering, eliminates some of the constraints imposed on mission planning. The capability to rapidly mate with and employ a variety of standard and special payloads supports the accomplishment of diverse and/or multiple mission objectives; the TAV is "missionized" by means of the capabilities of the payload(s) employed. The use of a standardized payload interface greatly simplifies the problem of

"re-rolling" the TAV system. During mission operations, trans-orbital maneuvers may be performed which provide the mission planner with additional degrees of freedom in assigning mission objectives.

Survivability: The speed and altitude regime of the TAV system make it inherently survivable.

MEASURES OF PERFORMANCE

MOPs are presented in the form of Performance Criteria Specifications, PCSs. The PCS is a formatted description of the context and content of each TAV System Function. The Crew Task(s) portion of the PCS has been prepared to have the appearance of a crew procedure. The last portion of the PCS, Specification for Successful Performance of Task, is, in essence, the actual MOP.

The PCS MOP description is composed of several interrelated sections:

Mission Phase: The mission phases of the notional TAV mission (Pre-flight, Takeoff, Climbout, Trans-Orbital, On-Orbit, De-Orbit, Approach, Landing, or Post-Flight) are presented in Section III, Mission Event Sequence.

System Function: The specific TAV System Function (Section IV) or capability being exercised in executing the mission plan for that Mission Phase.

Crew Task(s): The procedure followed by the TAV crew in accomplishing the TAV System Function.

Conditions: A description of the external and internal system states in force when the TAV System Function is being executed.

Specification for Successful Performance of Task: These are the quantitative metrics which are to be applied in determining the successful accomplishment of the Crew Task(s). They are defined in terms of speed (time), accuracy, errors, and expected workload. (Workload estimation is implicit in the PCS. The Crew Tasks portion of the PCS could be used as the basis for a projective application of the Subjective Workload Assessment Technique [SWAT]. In SWAT, workload is defined along three dimensions: time stress [T], mental effort [E], and psychological stress [S]. Three levels are explicitly defined for each of the dimensions. Experienced Operating Command crewmembers serve as subject matter experts [SMEs]. An individual SWAT scale is developed for each SME, based on his/her rank ordering of the 27 [3^3] combinations of the T,E,S descriptions using a mathematical procedure termed conjoint scaling. The SME is then required to provide T,E,S triplets for each Crew Task procedure. This is referred to as "event scoring." The SWAT rating is then converted into a SWAT workload value by means of the individual scale. The SWAT workload value is defined over the range of zero to 100 SWAT workload units. A second method of assessing crew workload from the PCS is based on estimating the time available [TA] for completing the entire Crew Task and the times required [TR] for the execution of each step in the procedure. The ratio of TR/TA, similar to a utilization ratio in queueing theory,

serves as the workload metric.)

PERFORMANCE CRITERIA SPECIFICATIONS

PCS descriptions have been developed for each of the System Functions identified in the MES and depicted in the IDEF0 charts. The PCS descriptions are, in essence, an initial development of crew procedures which might be employed to execute the required System Function. Just as the IDEF0 depictions represent one approach to implementing the System Functions, the PCS descriptions each represent one of several possible crew procedures which could be developed by the Operating Command.

The portion of the PCS which details the CREW TASKS is intended to suggest a crew procedure or checklist. It is not as complete as one which might be derived from an avionics manual since the TAV C/VI has not yet been thoroughly defined. Salient features of the C/VI (Master Modes, MPDs, etc.), which were identified in the Baseline TAV Description (Section II), have been incorporated.

The SPECIFICATION portion of each PCS is numbered so as to correspond directly to the individual actions called out under CREW TASKS. MOPs are defined in terms of speed and accuracy parameters for each step of the "checklist." The MOPs are based on engineering judgement and subjective assessments of three task attributes:

- Frequency of occurrence of the task
- Criticality of the task (with respect to

mission success or safety-of-flight)

- Perceived difficulty or complexity in task execution (a correlate of workload)

(The individual PCSs are presented in the same order as were the System Function descriptions [IDEF0 depictions] in Section IV.)

MISSION PHASE: Multiple

SYSTEM FUNCTION: CONFIGURE TAV

CREW TASKS:

1. Configure the C/VI (see below)
2. Tailor MPD Formats (see below)
3. Monitor situational awareness MPD formats (VSD, HSD)
4. Identify upcoming mission event as requiring a change in trajectory
5. Select TAV Configuration MPD Format (secondary screen accessed from Flight Control Subsystem MPD Format)
6. Observe current TAC control surface configuration
7. Monitor control surface reconfiguration
8. Verify new control surface configuration

(9. Perform manual override [if required])

CONDITIONS: The TAV may perform trajectory change maneuvers during the transition between mission phases or within a single mission phase. Control surface reconfiguration is an automated FLIGHT CONTROL SUBSYSTEM function. The crew anticipates the reconfiguration event, monitors the automated execution, while ready to manually override the automation in the event of a malfunction The crew's role is primarily to assure safety-of-flight.

SPECIFICATION:

1. Configure the C/VI is performed within +/- 30 sec of the beginning of any mission phase
2. The MPDs are tailored to optimize the availability

of critical information within 1 min of the start of a new mission phase

3,4. Situational awareness regarding an upcoming flight control maneuver should be attained at least 2 min prior to the initiation of that maneuver and with 0 % omissions

5. Selecting the proper MPD format screen by which to monitor a critical mission event should be performed at least 30 sec prior to that event and with 100 % accuracy

6. Observing the current flight control surface configuration should take no longer than 0.5 sec and should be performed with 100 % accuracy

7. Monitoring the execution of an automated function should take no longer than 1.0 sec and should be performed with 100 % accuracy

8. Verifying the correct outcome of an automated, mission critical function should take no longer than 0.5 sec and should be performed with 100 % accuracy

(9. Manual override to restore safety-of-flight conditions should take no longer than 0.5 sec to perform and should be accomplished with 100 % accuracy)

MISSION PHASE: Multiple

SYSTEM FUNCTION: CONFIGURE THE C/VI

CREW TASKS:

1. Monitor situational awareness MPD formats
2. Identify upcoming event as mission phase transition
3. Select appropriate Master Mode
4. Verify new C/VI configuration

CONDITIONS: Configuration of the C/VI is performed at the beginning of each mission phase. The specifics of the new MPD format screen arrangements (i. e., TAV subsystem displays on individual MPD surfaces) reflect the planned events of the new mission phase, their relative priorities, crew preferences, and crew confidence levels. Tailoring of the C/VI's response to a Master Function input, to reflect, these factors is possible.

SPECIFICATION:

1,2. Situational awareness regarding an upcoming mission phase transition should be attained at least 1.0 min prior to the initiation of of that transition and with 0 % omissions

3. Selection of the appropriate Master Mode button should take no longer than 0.5 sec and should be performed with 95 % accuracy

4. Verifying the correct system response to a Master Mode control input should require no longer than 1.0 sec and should be performed with 100 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: TAILOR MPD FORMATS

CREW TASKS:

1. Identify upcoming mission event as requiring access to MPD format(s) not currently activated
2. Activate required MPD format screen(s)
3. Verify that correct MPD format screen(s) now activated

CONDITIONS: Much of the "switchology" required to configure the C/VI for the changing tasks and priorities of each mission phase is accomplished through the Master Mode function (see PCS for CONFIGURE THE C/VI, above). Individual mission events, however, may well require that the crew access specific subsystems or information sources for relatively brief periods during a mission phase in order to accomplish or monitor a specific task. The crew must understand the relative priorities of each information source (MPD format screen) since one currently accessed format must be deactivated in order to bring the new MPD format to an active status.

SPECIFICATION:

1. Situational awareness regarding the availability of information or access to control inputs for an upcoming mission event should be attained at least 1.0 min prior to that event
2. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0

sec and should be performed with at least 80 % accuracy (i. e., one erroneous pushbutton in a sequence of five button pushes would be tolerated in accomplishing a non-mission critical task)

3. Verification that the required MPD format screen is correctly available should require no longer than 0.5 sec and should be performed with 100 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: MONITOR ENGINES

CREW TASKS:

1. Monitor situational awareness display formats
2. Identify upcoming mission event as engine mode transition event
3. Select Engine Management Subsystem MPD format screen
4. Observe current throttle settings and engine mode performance
5. Monitor engine mode transition
6. Observe new throttle settings and engine mode performance

CONDITIONS: Transitions between ramjet, scramjet, and rocket engine modes (including engine restart for de-orbit) are mission-critical events. Although the actual engine mode transition will (probably) be an automated system function, the crew must monitor each transition, assure that the new engine mode has been adopted, and assure that the performance of the new mode matches the expected performance.

SPECIFICATION:

1,2. Situational awareness regarding an upcoming engine mode transition should be attained at least 1.0 min prior to the occurrence of the event and with 0 % omissions

3. Accession of any MPD format screen from any other MPD format screen should require no longer than

5.0 sec and should be performed with at least 80 % accuracy

4,6. Observation of control settings and subsystem performance against precomputed nominal values should require no longer than 1.0 sec and should be performed with 95 % accuracy

5. Monitoring the execution of an automated subsystem function should take no longer than 1.0 sec and should be performed with 100 % accuracy

MISSION PHASE: Multiple

SUBSYSTEM FUNCTION: SERVICE PAYLOAD

CREW TASKS:

1. Select Payload Interface MPD format screen
2. Monitor payload servicing status
3. Identify deviations in payload servicing
(4. Select Payload Interface Service MPD format screen
5. Correct deviations in payload servicing
6. Monitor payload servicing status)

CONDITIONS: Payload servicing is a continuous, automated system function. The crew can intervene and manually perform this function either by choice or to correct for malfunctions/failures in automated servicing.

SPECIFICATION:

1,4. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy

2,6. Observation of payload servicing status against data base nominal values should require no longer than 1.0 sec and should be performed with 95 % accuracy

3. Deviations from nominal should be identified to within 5.0 % and should require no longer than than 1.0 sec for each parameter comparision

5. Deviations should require no longer than 5.0 sec to correct and should be corrected to within 5 % of the required nominal value

MISSION PHASE: Multiple

SYSTEM FUNCTION: MONITOR SUBSYSTEMS

CREW TASKS:

1. Select Subsystems MPD format screen
2. Observe subsystems modes and status
3. Identify degraded modes of operation
4. Select (specific) subsystem MPD format screen
5. Perform BIT, change subsystem states/modes

CONDITIONS: Monitoring subsystems is a situational awareness crew function. The crew can complement the automation provided by the "Self-Help" subsystem in performing diagnostics, troubleshooting, and implementing "workaround" procedures.

SPECIFICATION:

1,4. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec to accomplish and should be performed with at least 80 % accuracy

2. Observation of subsystem modes and states should require no longer than 1.0 sec to accomplish and should be performed with 95 % accuracy

3. Degraded modes of operation should require no longer than 1.0 sec to identify and should be identified with at least 95 % accuracy

5. Control inputs should require no longer than 0.5 sec to perform and should be accomplished with at least 95 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: PERFORM (FLIGHT) MANEUVER

CREW TASKS:

1. Monitor situational awareness display formats
2. Identify upcoming mission event as flight maneuver
3. Select Flight Control Subsystem MPD format screen
4. Select Engine Management Subsystem MPD format screen
5. Select Thermal Loading MPD format screen
6. Select Dynamic Pressure MPD format screen
7. Monitor (automated) execution of flight control maneuver

CONDITIONS: One or more flight control maneuvers may be performed during each mission phase. The Trajectory Manager computes the required flight path and the Flight Control Subsystem computes the required control (stick and throttle) inputs. Command (Flight Director) steering, computed by the Flight Control Subsystem, are provided to the crew on the VSD and HSD.

SPECIFICATION:

1,2. Situational awareness regarding an upcoming flight maneuver should be attained at least 2.0 min prior to the initiation of that event and be achieved with 0 % omissions

3-6. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy

7. Monitoring the execution of an automated function should take no longer than 1.0 sec and should be performed with 100 % accuracy

MISSION PHASE: TAKEOFF/LANDING

SYSTEM FUNCTION: RETRACT/DEPLOY LANDING GEAR

CREW TASKS:

1. Observe that a within-nominal TAKEOFF (LANDING) has been accomplished
2. Move Deploy/Retract Landing Gear Lever to Retracted (Deployed) position
3. Verify proper landing gear retraction/deployment

CONDITIONS: Compliance with safety-of-flight nominals is a mission-critical crew function. The crew can abort an off-nominal TAKEOFF or perform a "go around" maneuver to correct an out-of-nominal landing approach.

SPECIFICATION:

1. Monitoring of safety-of-flight parameters on the VSD should take no longer than 0.5 sec and should be performed with 100 % accuracy
2. Operation of a dedicated control should take no longer than 0.5 sec and should be performed with 100 % accuracy
3. Verification of landing gear state should require no longer than 0.5 sec to accomplish and should be performed with 100 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: COMMUNICATE: TRANSMIT

CREW TASKS:

1. Identify upcoming mission event as requiring transmission of voice, data, and/or imagery
2. Perform TAILOR MPD FORMATS to activate Communication Subsystem MPD format screen
3. Verify communications link between TAV and MILSTAR satellite constellation
4. Select nodes to receive transmission
5. Perform TAILOR MPD FORMATS to activate Data Base Management Subsystem MPD format screen
6. Select message/data set to be transmitted
7. Verify message is in transmission queue
8. Verify message security protection
9. Initiate transmission
10. Monitor acknowledgement(s) of message receipt

CONDITIONS: Communication transmissions are a major benefit of a manned TAV system. The crew can provide their "on-the-scene" observations regarding TAV status and operational effectiveness, and acknowledgements to Command and Operations Centers regarding advisories and updates to the mission plan. With the possible exception of communications blackouts experienced only at very high Mach numbers, the TAV is in constant link-up with the MILSTAR relay satellite system. Antenna pointing (up-link) and satellite protocol "hand-shaking" are automated.

SPECIFICATION:

1. Situational awareness regarding a preplanned communications event should be attained at least 2.0 min prior to that event and with 0 % omissions

2,5. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy

3,7,10. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 95 % accuracy

4,6,9. Activation of a single control input should take no longer than 0.5 sec and should be accomplished with 90 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: MONITOR TRAJECTORY

CREW TASKS:

1. Select Trajectory Management MPD format screen
2. Observe actual trajectory in comparison to computed trajectory
3. Observe flight director command symbology on VSD
4. Select Thermal Loading MPD format screen
5. Observe heat loads and gradients on TAV
6. Select Dynamic Pressure MPD format screen
7. Observe dynamic pressure loads

CONDITIONS: Although TAV trajectory management is highly automated, the crew must maintain a high level of situational awareness regarding the effectiveness of the automation. The crew should be aware of any "out-of-nominal" trajectory management conditions. (These conditions might include excessive flight control lags in responding to maneuver commands.)

SPECIFICATION:

1,4,6. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy (It is assumed that the VSD is always activated at at least one of the two crew positions)

2,3,5,7. Observation of situational awareness information should take no longer than 1.0 sec to accomplish and should be performed with 95 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: STABILIZE TAV

CREW TASKS:

1. Perform TAILOR MPD FORMATS to activate the Trajectory Management MPD format screen
2. Observe current trajectory state and compare them with the computed values
3. Apply flight control inputs (as required)
4. Verify corrected trajectory state

CONDITIONS: Fine adjustments to the TAV's trajectory are accomplished by means of the flight control surfaces (endoatmospheric) or small rocket engines (exoatmospheric). Stabilization may be required in preparation for a trajectory change such as a trans-orbital maneuver, ascent to/descent from orbit, or prior to the deployment of a P/L or orbital rendezvous with a second space asset. The objective is to achieve velocity vectors which very closely match those computed during mission planning. If the initial conditions are achieved as planned, then the subsequent dynamic event will be accomplished to within close tolerances.

SPECIFICATION:

1. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy

2,4. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should

be performed with 95 % accuracy

3. Activation of a single control input should take no longer than 0.5 sec and should be accomplished with 90 % accuracy

MISSION PHASE: On-Orbit Operations

SYSTEM FUNCTION: OPEN/CLOSE PAYLOAD BAY DOORS

CREW TASKS:

1. Activate P/L Bay Operations MPD format screen
2. Verify current P/L Bay door status
3. Initiate Open/Close Bay Doors control input
4. Verify new P/L Bay door status

CONDITIONS: Opening of the P/L bay doors is required for the operation of certain P/Ls and for the deployment of P/Ls being inserted into higher orbits. This function is also integral to space asset recovery/repair operations and to space transportation missions.

SPECIFICATION:

1. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy

2,4. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 95 % accuracy

3. Activation of a single control input should take no longer than 0.5 sec and should be accomplished with 90 % accuracy

MISSION PHASE: On-Orbit Operations

SYSTEM FUNCTION: OPERATE PAYLOAD

CREW TASKS:

1. Identify upcoming mission event as requiring payload operations
2. Access P/L Bay Doors MPD format screen
3. Verify status of P/L bay doors (open)
4. Activate P/L Operation MPD format screen
5. Verify mode/option selections for P/L to be employed
6. Observe operation of the P/L
7. Verify completion of the P/L operations schedule
8. Verify status of P/L bay doors (closed)

CONDITIONS: P/L operations generally take place during the orbital portion of the TAV mission. The vehicle may be rotated (Perform TAV Stabilization) so that the P/L can point downward, toward the Earth. P/L operations are automated. The P/L guidance and control schedules are provided by the MDL. Actual operations are conducted based on accurate mission time and TAV positioning. The crew monitors all aspects of P/L operations.

SPECIFICATION:

1. Situational awareness regarding an upcoming payload operation mission event should be attained at least 5.0 min prior to the initiation of that operation and with 0% omissions

2,4. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and

should be performed with at least 80% accuracy

3,5,7,8. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 95% accuracy

6. Monitoring the execution of an automated function should take no longer than 1.0 sec and should be performed with 100% accuracy

MISSION PHASE: On-Orbit Operations

SYSTEM FUNCTION: DEPLOY PAYLOAD

CREW TASKS:

1. Identify upcoming mission event as requiring P/L deployment
2. Access P/L Bay Door MPD format screen
3. Verify P/L bay door status (open)
4. Access P/L Interface MPD format screen
5. Access P/L Eject/Boost MPD format screen
6. Monitor P/L ejection
7. Verify P/L bay door status (closed)

CONDITIONS: The TAV establishes itself in a low earth orbit. Certain P/Ls may be deployed co-orbitally. In this case, the TAV's orbit becomes that of the P/L. Other P/Ls require insertion into higher orbits. The TAV's orbital trajectory becomes the reference from which higher orbital insertion is accomplished. The TAV's P/L interface includes a P/L ejection mechanism. The P/L container includes a small rocket engine which, following ejection by and separation from the TAV, boosts the containerized P/L into the appropriate orbit. The actual sequence of P/L ejection and boosting is automated.

SPECIFICATION:

1. Situational awareness regarding an upcoming P/L deployment mission event should be attained at least 5.0 min prior to the initiation of that operation and with 0% omissions

2,4,5. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80% accuracy

3,7. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 95% accuracy

6. Monitoring the execution of an automated function should take no longer than 1.0 sec and should be performed with 100% accuracy

MISSION PHASE: On-Orbit Operations

SYSTEM FUNCTION: RECORD P/L DATA

CREW TASKS:

1. Identify upcoming mission event as requiring P/L data recording
2. Access P/L Interface MPD format screen
3. Access Data Management MPD format screen
4. Verify data recording schedule and moding
5. Monitor data recording

CONDITIONS: An on-board imagery and data recording capability is provided. Data may be subsquently transmitted to a Control Center or retained for Post-Flight exploitation.

SPECIFICATION:

1. Situational awareness regarding an upcoming data recording mission event should be attained at least 5.0 min prior to the initiation of that operation and with 0% omissions

2,3. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80% accuracy

4. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 95% accuracy

5. Monitoring the execution of an automated function should take no longer than 1.0 sec and should be performed with 100% accuracy

MISSION PHASE: On-Orbit Operations

SYSTEM FUNCTION: ENGINE RESTART

CREW TASKS:

1. Identify upcoming mission event as requiring engine restart
2. Access Engine Management MPD format screen
3. Initiate engine restart (integrated into throttle)
4. Verify that restart has been accomplished

CONDITIONS: Refiring of the TAV's rocket engines is required to initiate the deorbiting maneuver. It must be performed from a stabilized orbital trajectory and according to the mission plan.

SPECIFICATION:

1. Situational awareness regarding an upcoming engine restart mission event should be attained at least 5.0 min prior to the initiation of that operation and with 0% omissions
2. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80% accuracy
3. Activation of a single control input should take no longer than 0.5 sec and should be accomplished with 90% accuracy
4. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 100% accuracy for mission critical actions

MISSION PHASE: Multiple

SYSTEM FUNCTION: ADJUST TRAJECTORY (MANUAL)

CREW TASKS:

1. Access the Flight Control MPD format screen
2. Invoke the Manual Override selection
3. Respond to Flight Director commands on VSD
4. Apply flight control inputs (as required)

CONDITIONS: This is a manual backup for the automated trajectory/flight path management capability. The primary flight controls are the stick and throttle (as in a conventional airplane).

SPECIFICATION:

1. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy
2. Activation of a single control input should take no longer than 0.5 sec and should be accomplished with 90 % accuracy
3. Deviations between Flight Director command values and TAV trajectory state should require no longer than 0.5 sec to assess and no longer than 5.0 sec to correct and should be corrected to within 5 % of the required nominal value
4. Control inputs should require no longer than 0.5 sec to perform and should be accomplished with at least 95 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: COMMUNICATE: RECEIVE

CREW TASKS:

1. Observe a receipt of message advisory on MFD
2. Access Communications MPD format screen
3. Select message from Received Messages queue
4. Read message
5. Perform required actions

CONDITIONS: Receiving of communications from mission and operational command centers may be preplanned or as required. A manned TAV system affords the command authorities with positive control over all aspects of the mission. The planned flight trajectory, P/L operating schedules, etc., may be modified/updated as required by possibly changing command authority objectives. Force direction messages, transmitted by the command and control centers, are acknowledged by the TAV crew as they are received and responded to. Message reception (communication link management) and message acknowledgement are automated functions.

SPECIFICATION:

1. Situational awareness regarding an incoming communication should take no longer than 0.5 sec to attain and should be accomplished with no more than 5 % omissions
2. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and

should be performed with at least 80 % accuracy

3. Control inputs should require no longer than 0.5 sec to perform and should be accomplished with at least 95 % accuracy

4,5. (As required by message content)

MISSION PHASE: Multiple

SYSTEM FUNCTION: UPDATE MISSION PLAN

CREW TASKS:

1. Observe that a received message requires a change to the planned mission
2. Verify acknowledgement of message receipt
3. Access Data Management Subsystem MPD format screen
4. Observe mission update message in pending message queue
5. Access mission update message
6. Assess impact of mission update(s) on mission plan
7. Consent to mission update
8. Verify that MDL update has been accepted/processed by Data Management Subsystem
9. Observe updated mission plan on VSD and HSD

CONDITIONS: This system capability is exercised when a communication is received from the mission control center which directs a change to the mission plan. Because of the level of automation in the Communications, Data Management, and Flight Control Subsystems (among others), the crew's role is to acknowledge the redirection message, providing explicit consent to implementing the required changes to mission plan.

SPECIFICATION:

1. Situational awareness regarding an incoming communication should take no longer than 0.5 sec to attain and should be accomplished with no more than 5 % omissions

2. Monitoring the execution of an automated function should take no longer than 1.0 sec and should be performed with 100% accuracy

3. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy

4. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 100% accuracy for mission critical actions

5. Control inputs should require no longer than 0.5 sec to perform and should be accomplished with at least 95 % accuracy

6. Situational awareness regarding updated mission plan should require no longer than 30 sec to achieve and should be attained with at least 95 % accuracy

7. Control inputs should require no longer than 0.5 sec to perform and should be accomplished with at least 95 % accuracy

8. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 100% accuracy for mission critical actions

9. Situational awareness regarding the mission plan should take no longer than 5.0 sec to attain and should be accomplished with 95 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: UPDATE PAYLOAD GUIDANCE AND CONTROL

CREW TASKS:

1. Perform UPDATE MISSION PLAN System Function
2. Access P/L INTERFACE SUBSYSTEM MPD format screen
3. Observe updated P/L guidance and control portion of mission plan

CONDITIONS: This is a special case of the UPDATE MISSION PLAN System Function. The update to the P/L guidance and control portion of the MDL may affect the P/L operations schedule or, if appropriate, the P/L's orbit.

SPECIFICATION:

1. (See above)
2. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and should be performed with at least 80 % accuracy
3. Situational awareness regarding the mission plan should take no longer than 5.0 sec to attain and should be accomplished with 95 % accuracy

MISSION PHASE: Multiple

SYSTEM FUNCTION: RESPOND TO WCA

CREW TASKS:

1. Observe that WCA annunciation has been generated
2. Access "SELF-HELP" SUBSYSTEM MPD format screen
3. Observe affected subsystem(s)
4. Command subsystem diagnostics (as required)
5. Observe results of diagnostics
6. Perform troubleshooting on affected subsystem(s) (as required)
7. Observe results of troubleshooting
8. Adopt degraded mode of operation (if required)

CONDITIONS: WCA annunciations are generated by the "SELF-HELP" SUBSYSTEM as required. Depending on the severity of the condition, the crew response may range from (implicit or explicit) acknowledgement of the condition to actively performing (additional) diagnostics on and attempting to "troubleshoot" the problem subsystem. In many cases, the WCA information will primarily be used by ground support personnel in performing Post-Flight maintenance on the TAV subsystems.

SPECIFICATION:

1. Situational awareness regarding WCA annuciations should take no longer than 5.0 sec to attain and should be accomplished with no more than 5 % omissions
2. Accession of any MPD format screen from any other MPD format screen should require no longer than 5.0 sec and

should be performed with at least 80 % accuracy

3,5,7. Observation of subsystem states, modes, or selected options should require no longer than 1.0 sec and should be performed with 100% accuracy for mission critical actions

4. Control inputs should require no longer than 0.5 sec to perform and should be accomplished with at least 95 % accuracy

6. Control inputs should require no longer than 0.5 sec to perform and should be accomplished with at least 95 % accuracy

8. (See CONFIGURE C/VI System Function)

SECTION VI

CONCLUSIONS

The IRA process of:

- defining a baseline system description (Section II)
- developing a mission event sequence (Section III)
- identifying system functions and positing a system avionics architecture (Section IV)
- deriving measures of performance (Section V)

was successfully applied as the first phase of the crew system design process for a future TAV system. The process facilitated the identification of TAV-unique subsystems (e. g., Thermal Management, "Self-Help," P/L Interface) which must receive special attention during the design and refinement of the actual C/VI.

The methods employed during the conduct of the IRA (Concept Map, IDEF, PCS) demonstrated their individual utility and supported a synergistic approach to knowledge acquisition and representation, system function identification and allocation, and definition of the role of the TAV crew. Moreover, they supported a systems engineering approach to the initial conceptual design of the TAV C/VI. The IRA methodology also provided opportunities for generating collateral products. A technical memorandum regarding an approach to mission planning for TAV operations was developed during the course of the effort and provided to several Air Force agencies. Initial requirements for a TAV crew training system were also identified and

documented in a published technical paper (Kuperman and Sobel, 1992).

When a TAV system is actually developed, it will exhibit unique operational capabilities based on unique technologies which are only now being developed and demonstrated. It will require a unique C/VI to fully capitalize on the flexibility, positive control, judgement, and additional capabilities afforded by a knowledgeable, trained, and proficient aircrew.

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